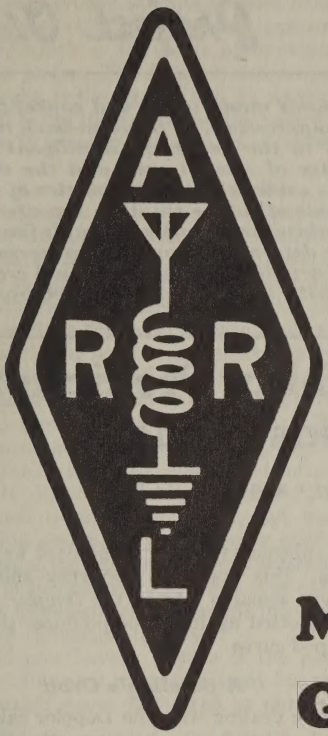

Member's Guide to Amateur Satellites

A collection of background articles published as a membership service by the American Radio Relay League, Newington, Connecticut 06111

QST:

Making Your Own Orbital Predictions from Doppler Measurements, March, 1962.
Australis-Oscar 5 – Where It's At, October 1969.
An Aid for Plotting Satellite Orbits, March 1970.
Amateur Space Communications – A Status Report, March 1970.
Are You Ready for the Coming DX Openings, March 1972.

ARRL *Handbook:*

Space Communications, 50th edition.

Amsat *Newsletter:*

Equipment Recommended for Operation with the Amsat-Oscar B Radio Amateur Satellite.
Design and Operation with the Oscar 6 Two-to-Ten Meter Repeater.
Helix Antenna Guidlines.
A Simple Approach to Oscar Communication Calculations.

As the radio amateur enters the space age, he finds many terms and concepts that are as strange and unreal to him as "sideband suppression," "front-to-back ratio," and "diode ring modulator" would have been to the well-read, intelligent radio amateur of 1927. A practical, working knowledge of space terms, and the orbital mechanics of a satellite, are of immense help in understanding the antics of Oscar I and II, and will be a "must" if use is to be made of future amateur repeater-type space satellites. This article covers the ABCs of orbital mechanics in simple language and shows how these parameters may largely be determined from the universal tool of space scientists — the Doppler curve. A second article will deal with actual creation of the Doppler curve — something you can do with home-brew Doppler equipment!

Making Your Own Orbital Predictions From Doppler Measurements

BY EDGAR A. HILTON,* W6VKP

From Doppler data, each radio amateur can determine the *time of closest approach* (t.c.a.) and the *slant range* (or straight-line distance) from satellite to receiving station. From this, orbital predictions can be easily made with reasonable accuracy. When data are available from two tracking locations, the satellite *height* and *position* can be determined. The equipment necessary for the Doppler measurements is simple, and directional antennas and frequency standards are not necessary.[1]

As a satellite beacon approaches a receiving station, the apparent transmitted frequency is raised. This is because the velocity of the satellite adds to the velocity of wave propagation. As the satellite passes the point of closest approach to the receiving station, its motion is perpendicular to the path of signal reception and the true transmitted frequency is received. Similarly, as the satellite recedes, the apparent transmitted frequency will be lowered, as the velocity of the satellite subtracts from the velocity of wave propagation. This apparent frequency shift of the received signal is termed the *Doppler shift*, and when plotted against time produces the typical S-shaped curve.

A Satellite's Orbit

Before dealing with the Doppler calculations, let us look briefly at a few properties of the orbit of a satellite. If the earth were a perfect sphere the orbit of a satellite would be essentially fixed in space while the earth rotated within the orbit. In addition, the satellite would follow a path such that the plane of the orbit would pass through the earth's center. The path as projected on the earth's surface would be a great circle if the earth did not rotate.

To be in orbit, a satellite must have an average orbital velocity such that its centrifugal force just balances the force of gravity. The orbit can also be considered as a ballistic trajectory, with the satellite always "falling" toward the center of the earth. As it falls, the earth curves away and the satellite therefore continuously falls around the earth.

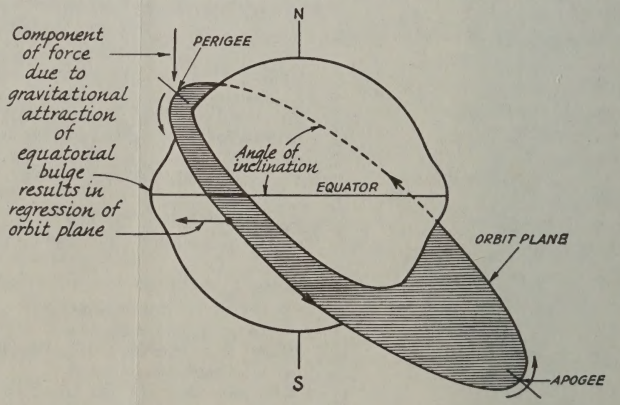

Fig. 1—The plane of the satellite orbit regresses in a westward direction due to the earth's equatorial bulge. The apogee and perigee swing around the orbital plane in an easterly direction.

* Hewlett-Packard Company, Palo Alto, California.

[1] Methods will be described in an article by D. E. Norgaard, W6VMH, to be published in a subsequent issue of *QST*.

The orbit of a typical satellite is more likely to be elliptical than circular. The closest approach to the earth, which is the point of minimum height, is the *perigee*. The farthest distance, or maximum height, is the *apogee* (Fig. 1). At perigee, the satellite has its greatest orbital velocity, which carries it to apogee, the point of lowest velocity.

The earth is not perfectly round and has, in addition, a bulge around the equator due to the rotation. This oblateness of the earth results in greater gravitational attraction in the equatorial regions than at the poles. The enhanced equatorial gravitation attracts the satellite toward the equator and tends to tip its orbit plane as shown in Fig. 1. The orbiting satellite, acting like a gyro, reacts at right angles, which results in a movement of the plane of the orbit to the west. This is the westward *regression* of the orbit plane. The bulge of the equator also causes the orbit to turn on its own plane, swinging the apogee and perigee in an easterly direction. Orbits, of course, are not all inclined as shown in Fig. 1, but may range from full equatorial to full polar orbits. The regression of the plane of the orbit increases as the angle of inclination [2] decreases. The easterly swing or movement of the perigee increases as the angle of inclination increases.

You should now have a picture of the path taken by a satellite as it travels endlessly but not aimlessly through space. Let's look at our own satellite, Oscar.

The Orbit of Oscar I

Oscar I was launched around noon in the month of December in a near-polar orbit. Its direction was *south* from the launching site. After passing over Antarctica it entered the darkness of the earth's shadow and traveled northward. As it crossed the equator in this *south-to-north* direction, orbit No. 1 began. Upon crossing the north polar region, Oscar again entered daylight and proceeded southward to the latitude of the launching site. During this time of flight, however, the launching site moved east because of the earth's rotation under the satellite's orbit. Thus the satellite path, as viewed from the launching site, appeared to have moved to the west. Continuing the flight, Oscar again crossed Antarctica following in its own previous path. However, orbit No. 1 (the first revolution of Oscar) was not completed until the satellite again crossed the equator traveling from south to north. Thus, all revolution or orbit numbers are started on the equatorial crossing of the south-to-north pass.[3]

About 10 hours (several revolutions) later, Oscar crossed the equator going from south to north in darkness, and was again observed in the vicinity of the launching site. This night observation, however, viewed the satellite from the opposite side of the orbit, as the earth had rotated in the interim.

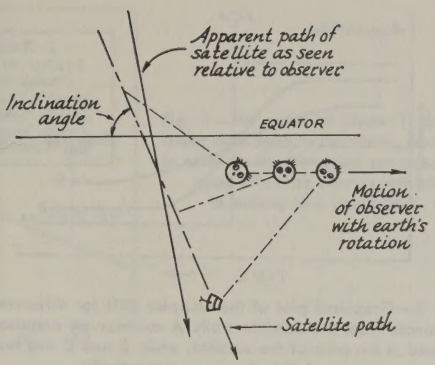
Apparent path of satellite as seen relative to observer
Inclination angle
EQUATOR
Motion of observer with earth's rotation
Satellite path

Fig. 2—The apparent path of the satellite as seen by an observer differs from the angle of inclination. The motion of the observer caused by the earth's rotation tips the angle as plotted on a map.

Let's look closer at a portion of the satellite orbit. Oscar was launched at an *angle of inclination* of about 82 degrees (Fig. 1). Therefore, the satellite crossed Antarctica to the east of the south pole as viewed on a world map looking down at the launching site. During a pass, the observer sees an apparent angle of inclination which differs from the true angle because of the observer's motion with the earth's rotation, as shown in Fig. 2. This difference varies with latitude, inclination angle, and the satellite velocity. For Oscar I, this difference was about 3.5 degrees at the equator, which places the *apparent* track (angle of inclination) on the map at about 85.5 degrees. For other locations on earth the difference is less. For high-altitude satellites this effect will be greater.

Doppler Measurement

Let us assume it is possible to place your receiving antenna within a few feet of the beacon satellite's orbit. In this case the received frequency, as the satellite approaches the antenna, will be raised, and as the satellite passes by the antenna the frequency abruptly lowers. Plotting this frequency change graphically against time produces a step function as shown in curve *A* of Fig. 3.

However, your receiving antenna cannot be placed in the path of the satellite, and the Doppler shift as observed from the ground will appear more like curves *B* and *C* of Fig. 3. Curve *B* illustrates a near pass and curve *C* shows a more distant pass. It should be noted that the greatest rate of change of frequency occurs in all three cases when the satellite is closest to the receiving antenna and its path is perpendicular to the path of the received signal. This is the *point of closest approach* (p.c.a.). The *time of closest approach* (t.c.a.) can be determined then as the time when the frequency was changing the fastest. For

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[2] The angle of inclination is the angle in degrees made by the intersection of the orbit plane and the plane of the equator, and is also the highest latitude that the satellite will reach.

[3] The portion of Oscar's voyage from time of launch, across Antarctica and north to the equator may be thought of as "Orbit No. 0."

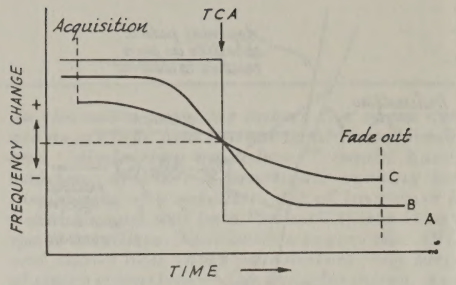


Fig. 3—Graphical plot of the Doppler shift for different distances from the satellite path. A assumes an antenna placed in the path of the satellite, while B and C are for near and distant passes, respectively.

practical purposes, the time of closest approach (t.c.a.) is also the middle of the Doppler curve or a point equal to one-half of the total Doppler frequency change.

Doppler data received from a passing satellite and plotted in graphical form similar to Fig. 3 permit the amateur to get a rough idea of the accuracy of the data, since all the plotted points should lie on a smooth uniform curve. This Doppler curve reveals p.c.a. and t.c.a., and will also be useful in the calculations of slant range as covered later in this article.

The Satellite Period

An *approximate period*, which is the time required to complete one revolution, can be calculated from the t.c.a. of successive passes. As an example, the t.c.a. of pass No. 134 of Oscar I was measured as 92 minutes 9 seconds later than that of pass No. 133, which would indicate an approximate period of 92 minutes 9 seconds. Bear in mind that this is computed from times of closest approach, not latitude crossings, and is only approximate and not the true period. Since the satellite orbit is inclined as shown in Fig. 4, the t.c.a. measurements are perpendicular to the orbit path; this gives a time difference between t.c.a.'s which is greater than the true period. The period observed in this manner should be corrected to the latitude crossings to be of maximum use. The true period is always calculated from some latitude line, usually the equator.

If the period is computed over a day's time — that is, from a pass today to a like pass tomorrow — the error in the period is reduced for two reasons. First, like passes a day apart (pass No. 133 and No. 149) will have less longitudinal separation than successive passes (No. 133 and No. 134) by one-half or less, as shown in Fig. 4. Second, the resulting computed period will be averaged by the total number of passes during that day. In the case of Oscar, the t.c.a. of pass No. 149 was 24 hours 25 minutes later than that for pass No. 133. It was also 16 orbits later. This gives a period of 91 minutes 34 seconds, which is substantially different from the period calculated from successive passes. Similarly, the period can be obtained even more accurately by averaging over longer intervals of time. However beware of a changing orbit! Oscar I was in a decaying orbit, accelerating and coming closer to the earth. This resulted in a continuous shortening of the period as the days went by.

Making Your Own Orbital Predictions

Once the period of an orbit has been established, you can make fairly accurate orbital predictions for your location. Two items are desired in the predictions, the t.c.a. for future passes and the approximate position of the satellite at t.c.a. As mentioned in the previous section, passes No. 134 and No. 149 for Oscar I were approximately one day apart, or 24 hours and 25 minutes apart. Therefore, a pass which is 16 orbits later than No. 149 (pass No. 165) will be 24 hours 25 minutes later, or to say it another way, 25 minutes later the following day. (This is, for the moment, neglecting any changes in the satellite orbit.) Generally, a pass earlier or a pass later can also be received. This is convenient when it comes to checking out your crystal ball. Pass No. 164 in the preceding example would be approximately one period earlier than the computed t.c.a. of No. 165. Likewise, pass No. 166 would be about one period later. If you can pinpoint a few successive passes "on the nose," you are in business!

A Changing Orbit

A low-altitude satellite may be subject to drag from the earth's atmosphere, which causes it to circle closer and closer to the earth. The time of each revolution, or period, then will be continuously shortening. When this occurs the progressively shorter periods should be taken into account in the orbital predictions. If the period is calculated each successive day it will soon be evident that each period reading is less than the preceding one and that the orbit is *decaying*. The amount of decay, or rate of change of the period can easily be seen graphically by plotting periods against orbit number as you

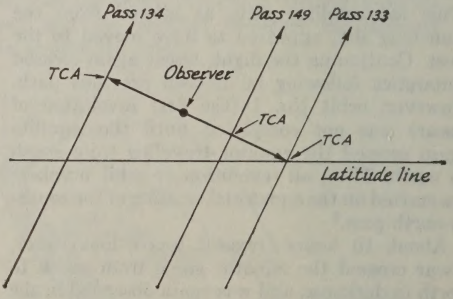


Fig. 4—The time difference between t.c.a.'s of successive passes, such as Nos. 133 and 134, is only an approximate period since it is measured perpendicular to the orbit rather than along a latitude line. More accurate results can be had from day-to-day passes such as Nos. 133 to 149. The smaller error here is further divided by the number of orbits during the day.

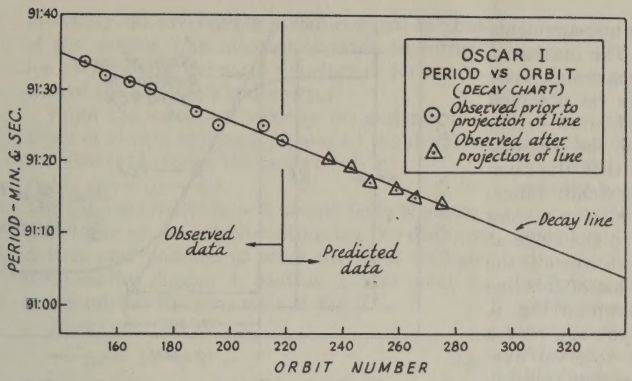


Fig. 5—The orbit of Oscar 1 circled closer and closer to the earth, resulting in continuously-shortening periods. This type of decay chart is helpful in making time predictions.

collect additional data. Fig. 5 shows this plot for Oscar I. This chart was made up at about the time of orbit No. 220, the decay line drawn in and projected to the right of orbit No. 220. The following six measurements fell reasonably close to the line. In making predictions this sort of decay chart will be an aid in predicting the period of future passes.

The Position of the Satellite

The expected position of the satellite at your t.c.a. can be computed from the rotation of the earth and the satellite's period. This is *expected* position, since the satellite may deviate slightly from your prediction because of the regression of the orbit plane. The earth revolves through 15 degrees of arc per hour or ¼ degree of arc per minute. During one satellite revolution the earth rotates through an arc equal to ¼ degree multiplied by the satellite period expressed in minutes. Each successive pass then will be farther west by ¼ period. For example, if Oscar passed 120 degrees west longitude during revolution No. 149, its next pass is expected at ¼ × 91:34 (period) or approximately 23 degrees farther west, or 143 degrees west longitude.

The satellite's orbit is not necessarily an even submultiple of a day, and it has already been determined that Oscar's 16th pass after No. 149 was 24 minutes later the next day. During this 24 minutes, the earth revolves through ¼ degree of arc per minute, which places the next day's pass 6 degrees west of this day's pass. Thus Oscar I's track upon the earth progresses westward on each succeeding day because its period is slightly greater than 90 minutes. If the period were 89 minutes, for example, the track upon the earth would progress eastward each day. If the period were exactly 90 minutes, the track on each successive day would fall upon the same location at equivalent times.[4]

The angular displacement of each day's corresponding pass and the displacement of successive revolutions, together with the time projections, can yield predictions several days in advance with good reliability. After several days of tracking you may notice a deviation between projected satellite position and the position established from measurements (to be covered later in this article). This is the regression of the orbit plane. Once known, the effect of regression can be included in order to correct your position predictions.

[4] There are other periods, of course, where this statement is true. A period of 96 minutes or 15 revolutions per day instead of 16 is an example.

Velocity of the Satellite

The velocity and height above the earth of a satellite are not necessarily constant as it revolves around the earth. The orbit is generally elliptical. At perigee, the velocity is greatest; conversely, at apogee the velocity is lowest. The velocity is important in computing the slant angle and the satellite's position and height. The eccentricity of the orbit is likely to be small compared with the size of the earth. For purposes of calculation, an assumed circular orbit will yield a reasonable average velocity. The velocity (V) then will be

$$V = \frac{D}{P} \text{ and } D = 2\pi(R + h) \qquad (1)$$

where D is the distance traveled during one orbit and P is the period of that orbit. R is the radius of the earth and h is the height of the satellite above the earth. You may not know the height during the first calculation and it will be necessary to assume a reasonable value. For low-orbit satellites an error in this assumption is not serious and can be corrected if the later solution for height differs greatly from that assumed. In calculating velocity, the greatest average velocity expected to be encountered is about 8 kilometers per second.

Calculating Slant Range

The minimum slant range, or distance between satellite and receiving station at p.c.a., can be obtained from your knowledge of the velocity, the maximum slope of the Doppler curve and the transmitter frequency. This is the only situation where the transmitter frequency enters into the calculations, and it need not be known to a high accuracy. For Oscar I calculations, a frequency of 145.0 megacycles was used. A 100-kilocycle error here will contribute less than 1/10 per cent error in the calculated slant range.

It would be nice if the rest of the measurements and calculations were this good! The maximum rate of frequency change or the maximum slope of the Doppler curve can easily be obtained graphically (Fig. 6). As explained in an earlier section of this article, a plot of the Doppler data will give an S-shaped curve with the t.c.a. at the mid-point of the frequency-shift range, or point of maximum slope. By placing a ruler through the t.c.a. point parallel to the slope at the mid-section, a line can be drawn which is the maximum slope. From the extension of this line construct a right triangle as shown in Fig. 6. From the two constructed sides you can read a frequency change and the time interval over which this change is taken. Dividing this frequency change by the time interval gives the maximum rate of change $\left(\frac{df}{dt}\right)$ of the received frequency.

The value of the maximum rate of change $\left(\frac{df}{dt}\right)$ will be under 100 cycles/sec./sec. for 2-meter signals. The accuracy of this figure will be directly dependent on the accuracy of the Doppler measurements, the plotted points, and the accuracy of the slope line drawn in. For best results, keep your pencil sharp!

The equation [5] for computing the minimum slant (r) is:

$$r = \frac{v^2}{\lambda \left(\frac{df}{dt}\right)} \qquad (2)$$

where v is the satellite orbit velocity

λ is the wavelength of the transmitted signal

$\frac{df}{dt}$ is the maximum rate of change in signal frequency as calculated above.

Watch the units on this one! If $\frac{df}{dt}$ is in cycles/sec./sec. and the wavelength (λ) is in meters, then the velocity (v) must be in meters/sec. The slant range will then be in meters, which can be easily converted to kilometers by dividing by 1000. It is suggested that calculations be done in the metric system because of the ease of making conversions. The final results can be converted to desired units.

Finally — The Satellite's Position and Height

Now with a little extra effort and a sharp pencil, it's possible to determine a few extra parameters about your satellite.[6] First, in order

[5] For the derivation of this equation see: Oliver, *Hewlett-Packard Journal*, November 1957, or Stahl, "Doppler Equation for Satellite Measurement," *Proceedings of the IRE*, May 1958, p. 915.

[6] The author is indebted to D. E. Norgaard, W6VMH, for suggesting this solution to the problem.

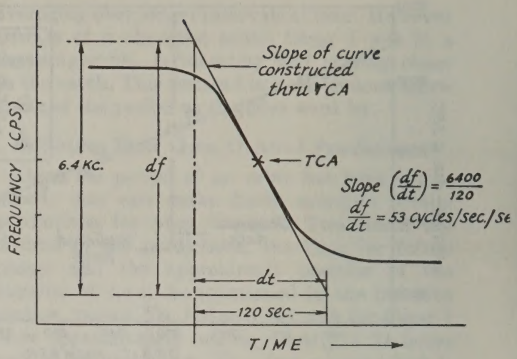


Fig. 6—The S-shaped Doppler curve. The time of closest approach and the maximum rate of change of frequency occur near the center of the curve. The slope is useful in calculating slant range.

to do what is to be proposed, a second tracking station will be necessary to obtain data for triangulation. This second station is best located at a ground distance of about 200 miles from your station to give a reasonable angle to the passing satellite. It is also desirable that the second station be located in an easterly or westerly direction from your station rather than north or south, if a polar-orbit satellite is expected. This may sound like a large order, but there is much interest in the Oscar program and all you need from the other station is his t.c.a. and slant range for the same pass that you copied. It is not necessary that the satellite pass between the two stations; it could be either side of both stations, but, of course, both stations must be able to copy the signal and obtain data from it.

The triangulation problem is shown in Fig. 7 in two sections, the plan view of the satellite path as it would appear drawn on a map, and the elevation view. The distance from station 1 to point x, $(a + b)$ as shown in both views, is

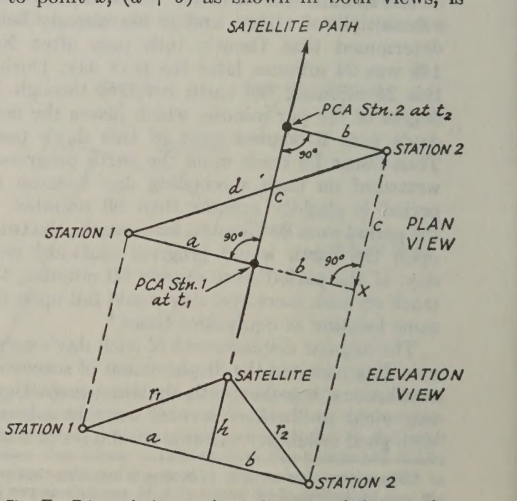


Fig. 7—Triangulation to determine ground distance from satellite path to two receiving stations.

in reality an arc having a radius equal to that of the earth's. (No attempt is made to correct for curvature of the earth's surface or for curvature of the satellite's trajectory.)

From the satellite's velocity (v) and the two times of closest approach (t_1 and t_2) the distance traveled (c) between the two p.c.a.'s is

$$c = v\,(t_2 - t_1) \tag{3}$$

The time difference $t_2 - t_1$ should be in the same time units as the velocity. Knowing the distance c, it is now possible to solve the right triangle bounded by Station 1, Station 2, and point x, as pictured in the plan view of Fig. 7.

Then

$$(a + b)^2 = d^2 - c^2 \tag{4}$$

$$\text{or } (a + b) = \sqrt{d^2 - c^2}$$

where d is the known ground distance between the two stations and can be computed from the latitude and longitude of each station or scaled from a map.[7]

In the elevation view two triangles are formed, one from each station. From these:

$$h^2 = r_1^2 - a^2 \text{ and } h^2 = r_2^2 - b^2 \tag{5}$$

where h is the satellite's height above the earth,

r_1 and r_2 are the slant ranges observed at stations 1 and 2, respectively, at their respective t.c.a.'s (see formula 2).

a is the ground distance from Station 1 to the satellite's position at p.c.a.

b is the ground distance from Station 2 to the satellite's position at p.c.a.

By combining these equations:

$$r_1^2 - a^2 = r_2^2 - b^2$$

or

$$r_1^2 - r_2^2 = a^2 - b^2$$

then

$$a - b = \frac{r_1^2 - r_2^2}{(a + b)} \tag{6}$$

By solving equations 4 and 6 simultaneously:

$$2a = \frac{r_1^2 - r_2^2}{(a + b)} + \sqrt{d^2 - c^2}$$

then

$$a = \tfrac{1}{2}\left[(a + b) + \frac{r_1^2 - r_2^2}{(a + b)}\right] \tag{7}$$

$$b = (a + b) - a \tag{8}$$

When solving these equations it is possible for the ground distance a or b to come out negative. If a should be negative, then the satellite passed to the left of Station 1 as viewed in Fig. 7, and conversely, if b is negative, it passed to the right of Station 2. When both a and b are positive, the pass was between the two stations. If both a and b are negative, it is best to start over! You goofed!

Now, having both distances a and b computed, the position of the satellite track is known and can be marked on a map. From equation (5) the expression for the satellite height is:

$$h = \sqrt{r_1^2 - a^2}$$

or

$$h = \sqrt{r_2^2 - b^2} \tag{9}$$

There have been a few assumptions here other than that Oscar's path is a straight line and that the earth is flat. These other assumptions involve velocity based on an assumed height, and slant range based on this velocity. But all these assumed values have now been computed. For those who wish to go farther, the computed values can be "plugged in" in place of those assumed and the whole process done over again. If the errors in assumed value were in the order of 10 per cent, the corrected values will be much improved. In this fashion you can "zero in" on the correct answer. The limiting factors will be the equations based on plane geometry and the accuracy of the original input data.

Remember that most of the numerical figures shown in this article are for Oscar I and that the period, inclination angle, height, and velocity are likely to be different for other satellites. Those parameters dealing with the earth's rotation we dearly hope will remain the same.

We had a lot of fun following Oscar on those sleepless nights. We enjoyed trying to see how closely we could predict future passes and even tried to predict the time of acquisition and fade. In a few cases the signal was acquired within a few seconds of the estimated time and we were rarely off as much as a minute. It was felt others can have fun at it, too, and this has been the inspiration for this article.

It is admitted that these calculations are only a first-order approach and that many refinements such as curvature of the earth, the orbit, and effects of propagation could be brought in to improve the accuracy. However, with this rough approach it was found that the t.c.a. can be predicted within a few seconds and slant ranges calculated to a probable 10 per cent. This is more than sufficient to prevent you from missing the next pass.

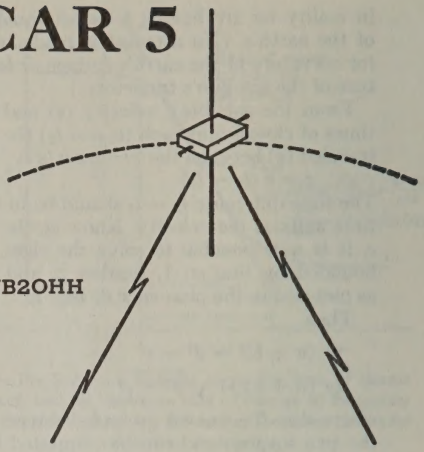
I would like to express my appreciation to Don Norgaard, W6VMH, for his participation and assistance in this program and the preparation of this article, to Dr. B. M. Oliver for his technical assistance and advice, and to the members of the HP Amateur Radio Club for their participation and support.

QST

[7] FAA sectional charts available at your local airport or from FAA, Washington, D. C., are excellent for this purpose. The scale of these maps is 1/8 inch per statute mile.

AUSTRALIS-OSCAR 5

WHERE IT'S AT



BY WILLIAM DANIELSON*

and SHELDON GLICK*, WA1IUO/WB2OHH

AUSTRALIS-Oscar 5 contains beacon transmitters operating at 144.050 and 29.450 MHz. The design and operation of the satellite were described in previous articles (see bibliography in *QST* for September 1969, pg. 47). The purpose of this article is to familiarize readers with satellite tracking techniques.

The numbers presented here are based on the TOS (Tiros Operational Satellite) orbit as an example. This orbit is a practical one since many amateurs track TOS satellites to obtain local cloud cover (APT) pictures, using information transmitted by W1AW on equatorial crossings of TOS satellites. News of the actual orbital parameters of Australis-Oscar 5 will be reported either in League Lines or by W1AW bulletin.

To facilitate your hearing Australis, W1AW will transmit, on its normal bulletin schedule (see page 116), the approximate times the satellite will be over selected areas. Additionally, for those interested in more precise tracking, the times and longitude of equatorial crossings will be transmitted. This article describes how to use the equatorial crossing data.

Getting Set Up

In order to track Australis-Oscar, you will need a few items not normally found in a ham shack. First, you will need a clean table. Once over this hurdle the rest is easy! Upon the table you will need a fairly large world map — large enough to be marked off at least every five degrees of longitude at the equator. A north polar stereographic projection is best. This is the type of map with the North Pole in the center.[1] Other types of maps can be used. But, try to avoid Mercator projection maps. Get a piece of clear plastic or glass to cover the map, a protractor, and some grease pencils for writing on the plastic or glass surface. Now, you are ready to start plotting Australis-Oscar's path.

Look at the scale on your map to determine how many miles to the inch. Find your location on the map and draw a circle with a radius of 2135 nautical miles (2455 statute miles) centered on your QTH. Unless you have an obstruction on your horizon, you will be able to hear the satellite when the point on the Earth's surface directly under the satellite (sub-satellite point) is within this circle. The longest pass you will be able to hear is one that cuts the circle in half by going almost directly over your head. Passes to the east or west of you will be of progressively shorter duration the farther east or west they are.

Where and When

The nearest pass to directly overhead will occur at about 1500 local standard time each afternoon, and again at about 0300 local standard time each morning. This is because the satellite will be in a "sun-synchronous" orbit. That is, the orbital plane maintains a constant orientation relative to the sun. Daylight portions of each pass will be from south to north (called the ascending node), darkness portions from north to south (descending node). The period of the orbit, i.e., the elapsed time between two consecutive equatorial crossings on the same side of the earth, will be 114 minutes.

The latitude of your location will determine how many consecutive passes each day and night you will be able to receive. If you live at the North Pole, you can receive every pass since the satellite will be in a near-polar orbit. If, however, you live at the equator, you could hope to hear a maximum of four passes per day — two during daylight and two during darkness. At 40° north latitude, which about bisects the United States, you can look forward to three or four consecutive passes each afternoon and morning, or, up to eight passes each day.

When To Listen

In order to find the satellite, you will need only two pieces of information not supplied by this article: the time of the equatorial crossing (ascending node) and its longitude. This data will be supplied by W1AW bulletins. The longitude of an equatorial crossing will be given in degrees west of Greenwich, the 0° or prime meridian. If

* Talcott Mountain Science Center for Student Involvement, Avon, Connecticut 06001.

[1] This will provide reliable indications for the Northern Hemisphere; amateurs in the Southern Hemisphere should use a South Polar projection. In general, such projections are useable for the hemisphere on which they are centered.

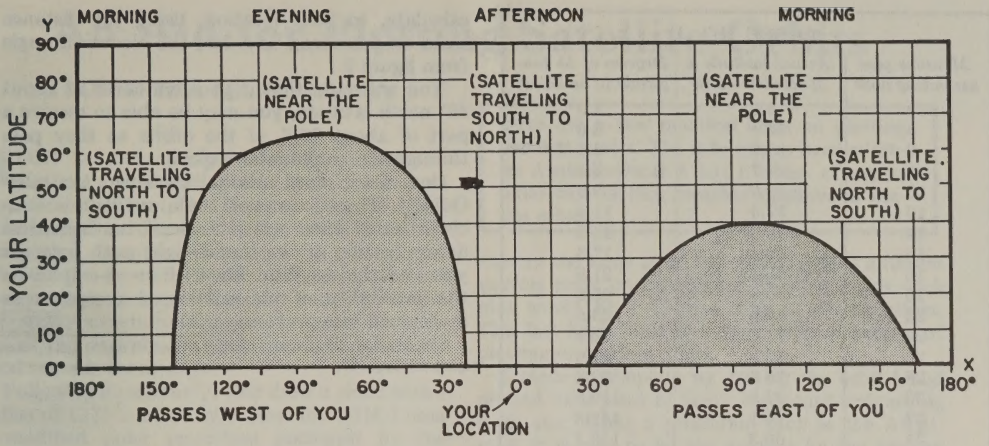


Fig. 1 — How to determine which passes you can hear.

Directions:

1. Locate your latitude on the y axis; draw a line horizontally across the graph from this point.
2. Determine how many degrees east or west of *your longitude* the equatorial crossing (ascending) will occur. Mark this point in the appropriate location on the x axis. Draw a vertical line from this point to the top of the graph.
3. If this line crosses the previously drawn line in an un-shaded area, you should be able to hear this pass. If, however, the intersection occurs in a shaded area, the pass will be unavailable to your location.

The approximate time of day (i.e. morning, afternoon, evening) for all passes is noted at the top of the graph. This is possible since the satellite is in a "sun-synchronous" orbit. The graph also indicates whether the pass is north-to-south, south-to-north, or near the pole at the time when you will hear it. Note that for the passes nearly 180° away from you, the south-to-north equatorial crossing occurs on the opposite side of the earth. Your acquisition of the satellite for such passes, will occur once the satellite has crossed near the pole and begun its north-to-south sweep.

this number exceeds 180°, the satellite then really is in east longitude according to your map. You would then have to subtract the given longitude from 360° to obtain the degrees of east longitude. Example: Ascending node is at 220° west longitude; so, 360° minus 220° equals 140° east longitude. Remember that all times will be expressed in GMT.

At this point we are ready to plot an orbital path. Let's suppose that your QTH is located near St. Louis, latitude 38.5°, west longitude 90°. Draw a circle on your map with a radius of 2135 nautical miles (2455 statute miles) centered on your location. Any satellite pass that crosses any part of this circle, you should be able to hear. The spread of equatorial crossings which will cross your acquisition circle can be found from figure 1.

Choose a pass which you intend to track and put a dot on the map at the point where it crosses the equator. Next, consult Table 1 to see that two minutes after crossing the equator, Australis-Oscar has gone north to latitude 6.2° and is 1.8° west of the equatorial crossing longitude. Find this point on the map and mark another dot. Repeat this step for each two-minute interval as the satellite travels, until you have a string of dots two minutes apart going across your acquisition circle. (Omit dots which occur prior to reaching and after leaving your range.)

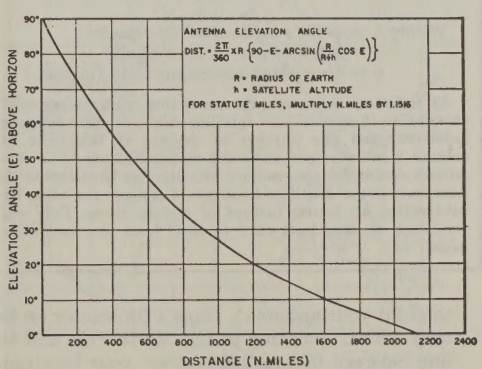


Fig. 2 — Antenna elevation angle *vs.* distance along earth to sub-satellite point.

Antenna Pointing

Now draw a line connecting the dots.

The points at which this line crosses your circle are the acquisition and loss times for this particular pass. Since you know the time of each dot, you can find these times to within about 30 seconds. To determine the azimuth heading for each two-minute point (i.e., the direction in which

TABLE NO. 1

Minutes past ascending node	*Actual latitude ϕ of satellite north*	*Degrees of $\Delta\lambda$ longitude to be added*
2	6.2°	1.8°
4	12.4	3.6
6	18.6	5.4
8	24.7	7.4
10	30.9	9.6
12	37.0	11.9
14	43.0	14.5
16	49.1	17.3
18	55.1	21.5
20	60.9	26.6
22	66.6	33.6
24	71.8	44.3
26	76.0	61.9
28	78.3	89.2
30	77.5	119.9
32	74.1	142.3
34	69.3	156.1
36	63.8	164.5
38	58.0	170.4
40	52.1	174.8
42	46.1	178.2
44	40.0	181.1
46	33.9	183.6
48	27.8	185.9
50	21.6	187.9
52	15.4	189.7
54	9.3	191.5
56	3.1	193.4
57	0	194.5

$$\phi = \text{ARCSIN}\left\{\left(\text{SIN } \iota\right)\left(\text{SIN } \frac{2\pi}{\rho}\tau\right)\right\}$$

$$\Delta\lambda = \text{ARCCOS}\left\{\frac{\text{COS}\left(\frac{2\pi}{\rho}\cdot\tau\right)}{\text{COS } \phi}\right\} + 0.25\,\tau$$

Where ι = orbit's inclination to equator
ρ = satellite period (114 min.)
τ = time after ascending node (in min.)

At indicated minutes past ascending node (equatorial crossing south to north) the satellite will be at north latitude indicated, and the number of degrees of longitude in column 3 must be added to the node longitude. The correction factor for the earth's rotation has been included. Amateurs in the southern hemisphere can use the table by subtracting all figures instead of adding them. This will work the satellite backward in time from the ascending node.

to point your antenna), place a protractor on the map with 0° pointing to the North Pole and the line between 0° and 180° set on your longitude. The midpoint of the protractor base should be on your latitude. If the pass is to your west, have the 90° mark point west; if to the east, the 90° mark will point east. Place a straightedge between your location and the point of the orbit for which you wish to compute, and read the degrees at the point which crosses the protractor scale. On passes to the east, this will be your antenna azimuth in compass degrees. If the satellite is to your west, subtract the protractor reading from 360° to determine the azimuth in compass degrees. Finally, to find the elevation of Australis-Oscar above the horizon, measure the distance from the sub-satellite point you wish to calculate, to your location, using the distance scale on your map and find the elevation angle from figure 2.

You will note that if you live north of about 40° north latitude, you may be able to receive a part of about 80% of the orbits as they pass through the north-polar regions.

One final word about tracking Australis-Oscar 5. The information contained in this article is based on a straightforward mathematical determination of the line-of-sight path between you and the satellite. We wish to re-emphasize the possibility of unusual signal reception as mentioned in a previous article.[2] QST

[2] Dunkerley, "Australis-Oscar 5 and You!" *QST*, August 1969, p. 69.

An Aid for Plotting Satellite Orbits

BY LAWRENCE A. EDLER,* WB6MVK

Here are a few practical ideas on plotting satellite orbits. The info relates particularly to Australis-Oscar 5 but it's also of use to amateurs tracking weather satellites in similar orbits.

MUCH has been written to aid the amateur in plotting and obtaining data from the various amateur satellites. The October issue of *QST* contained an excellent article by WA1IUO and W. Danielson[1] describing techniques for plotting the orbit of the Australis Oscar. In my own attempts to get ready for receiving this satellite I used several hypothetical examples in order to train myself to construct the orbital projections I would need to track the satellite.

Following directions[2], I first drew a circle with a radius of 1235 nautical miles from my QTH. I used a modified polar projection published by the ARRL centered on the central USA. I then proceeded to plot a hypothetical orbit assuming that the satellite crossed the equator at 100 degrees west longitude. I took the data listed on page 56 of the October *QST* and determined a point for each two-minute interval given in the table. By connecting these points I determined the possible path of the satellite. Whenever the orbit of the satellite passes within the circle, I am in business.

It then occurred to me that any plot of an orbit based on the same inclination and period would be exactly the same as all the others, given a different starting point on the equator. In other words, each plot would be a Chinese copy of all the others. This fact lends itself to a more efficient manner of plotting succeeding orbits.

I made a template by tracing the orbit I had plotted on a piece of heavy cardboard and cutting it to size. Using a projection such as the ARRL map, it is best to let the equator be the bottom side of the template, the ascending phase the right side and the decending phase the left side. By simply lining up the template with the correct longitude at the time of the satellite's crossing of the equator, a crayon can be used to trace that particular orbit.

I found the best projection was a straight polar projection. In my case it was an old aeronautical chart.[3] Here again I repeated the process used to

(Continued on page 18)

* 102 Northrop Place, Santa Cruz, CA 95060.

1 W. Danielson and S. Glick, "Australis Oscar 5 Where It's At," *QST*, pages 54-56.

2 Ibid.

3 Polar projection maps, called APT Plotting Charts, are available from Mr. Robert W. Popham, APT Coordinator, U.S. Department of Commerce, Environmental Science Services Administration, National Environmental Satellite Center, Washington, D.C. 20233.

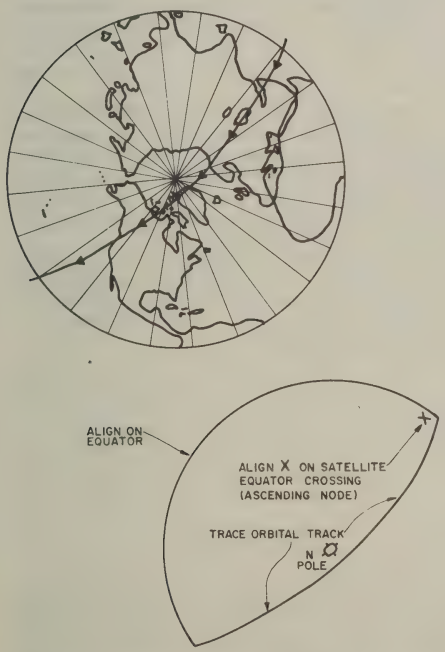


Fig. 1. Orbital plot of satellite and a template for a North Polar projection.

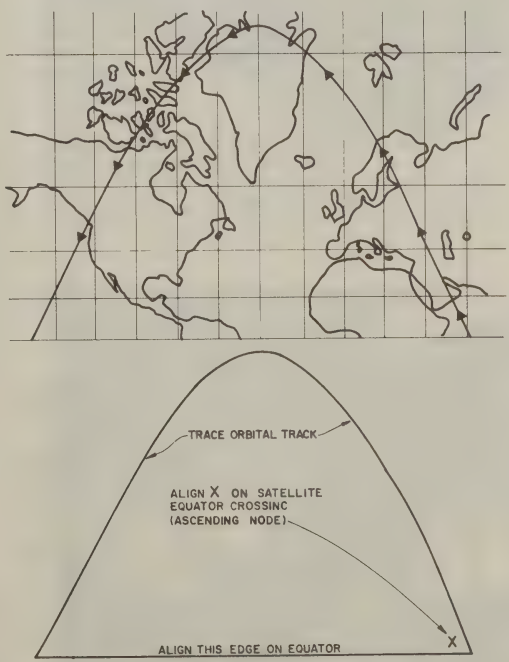


Fig. 2. Orbital plot of satellite and a template for a Mercator projection.

Amateur Space Communications — A Status Report

BY WILLIAM I. DUNKERLEY, JR.,* WA2INB,
AND PERRY I. KLEIN,** K3JTE

A DECADE WILL soon have passed since the first Oscar (Orbiting Satellite Carrying Amateur Radio), designed and built by West Coast hams, was launched on December 12, 1961. Now, in 1971, space communications still remains a new frontier for radio amateurs.

Perhaps as a reflection of our changing times and an emphasis on reaping the benefits of space technology for the masses, the priorities of ham space activities are being reoriented. The trailblazing satellite experiments of the 1960s now give way to amateur hopes for satellites for everyday use by hams for DXing, contesting, traffic handling, rag chewing, etc. Here then is the current status of amateur space communications plans.

Amsat-Oscar B

Amsat, the Radio Amateur Satellite Corporation (a non-profit amateur organization), is giving high priority to the development of long-lifetime, solar-powered satellites that can be used regularly and reliably by amateurs for routine communications. First in this series is Amsat-Oscar B (it will receive an appropriate numeral in the Oscar series upon launch). At present, a late 1971 or early 1972 launch is hoped for.

Following designs prepared by its Project Manager, Jan King, W3GEY, the satellite's internal structural assembly and modules have been fabricated at the facilities of W2QJT in Ithaca, New York. This represents the beginning of construction of actual flight hardware. Several panels of solar cells left over from NASA and ESSA satellite programs have been made available, and some are being reconfigured for use in A-O-B. Rechargeable nickel-cadmium batteries have also been made available. Together they are expected to make possible satellite operating lifetimes in excess of one year.

Several pieces of communications gear are under construction. A selection will shortly be made from completed items for inclusion in the A-O-B flight unit, expected to carry two repeaters and one or two telemetry systems. The gear under construction includes the following:

A four-channel, channelized, hard-limiting fm repeater is being breadboarded by members of the Wireless Institute of Australia's Project Australis who had been involved in the construction of Australis-Oscar 5. It is of the demodulation-remodulation type and employs 145.9 MHz for the uplink and 432.1 MHz for the downlink, with a satellite transmitter power output of one watt per channel.

A linear repeater with a bandwidth of 50 kHz is under construction by the Euro-Oscar group in Marbach, West Germany. Its input is 432.1 MHz, and output, 145.9 MHz, with ten watts output. It is designed for use with ssb, cw, am, fm, RTTY or SSTV, with as many stations as can fit within its 50-kHz passband.

Also being breadboarded by Amsat members in the U.S. is a linear repeater having an input of 145.9 MHz and an output of two watts around 29.6 MHz. It will handle any method of modulation permitted in these two bands.

*Assistant Secretary, ARRL.
**c/o Amsat, PO Box 27, Washington, DC 20044.

On a trip to the U.S., Wireless Institute of Australia (sponsors of Project Australis) president VK3KI met with Project Oscar officials. Shown from left are Project Oscar president K6LFH, VK3KI, Santa Clara Valley SCM W6VZT, and Oscar and ARRL board member W6ZRJ.

The WIA Project Australis group has developed an Oscar telemetry encoder which transmits directly in 850-Hz a.f.s.k. teletype format, for printout on an ordinary 60 wpm teleprinter. Any station having a tape reperforator will be able to send or retransmit the received data directly to Amsat headquarters for computer processing, or may decode the telemetry data using calibration information which will be made available prior to launch.

John Goode, W5CAY, has designed and breadboarded an Oscar telemetry encoder which transmits numbers directly in Morse Code, so that only pencil, paper and calibration information are needed for reception and interpretation of data from the satellite.

A breadboard of a command encoder capable of providing up to 35 separate command functions has been constructed by the Project Australis group. The command encoder is designed to provide a reliable and secure means of controlling the emissions of Oscar satellites to minimize any possibility of interference.

Project Oscar, Inc.

The pioneer organization in amateur satellites is the west-coast based Project Oscar, Inc. This group was responsible for the origination of the Oscar program and in particular for successes of Oscars one through four. Current Project Oscar activities include assistance with the A-O-B efforts. They have provided technical advice and aid in obtaining components, and also funds for necessary travel.

Project Oscar headquarters is Foothill College, Los Altos Hills, California. The group is working with the College on plans for incorporating an Oscar station in a campus space science facility. In addition to the above activities, Project Oscar has begun preliminary work on the development of another amateur satellite.

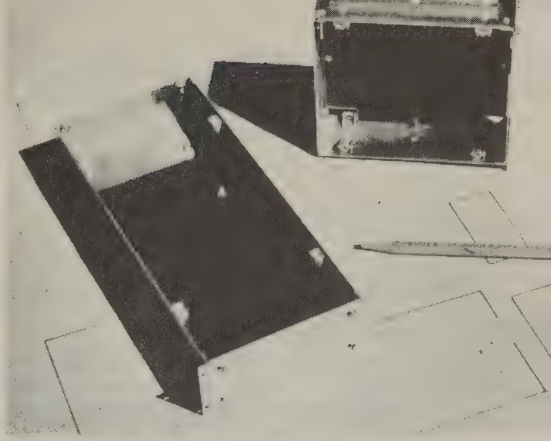
Moonray

Perhaps one of the most imaginative ham space projects to come along has been Moonray, a lunar-based amateur uhf repeater. Work on this project is under the direction of Nastar, K2SS, P.O. Box T, Syosset, NY 11791. When completed, Nastar hopes to have NASA carry Moonray to the moon on one of the remaining Apollo missions. A continuously-operational repeater with a one year or longer lifetime is the project objective.

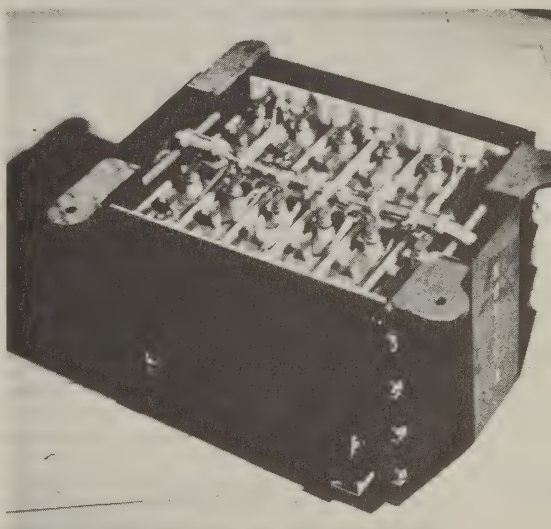
Moonray will contain a high-sensitivity, low-noise receiver, a signal processor, an identifier sending "SS" in Morse code, a timer-cycler-sequencer, six to eight channels of telemetry, and a laser receiver with optics. The up-link will be a 10-kHz passband centered at 439.9 MHz and the downlink will be a like bandwidth centered at 430.1 MHz. The repeater will be useful with all modes.

Count-down

As the time grows nearer for the operation of an amateur spacecraft, *QST* will carry full details and information on how to prepare your amateur station for use with a spacecraft repeater. Material is now being prepared in anticipation of a launch later this year or early next. QST

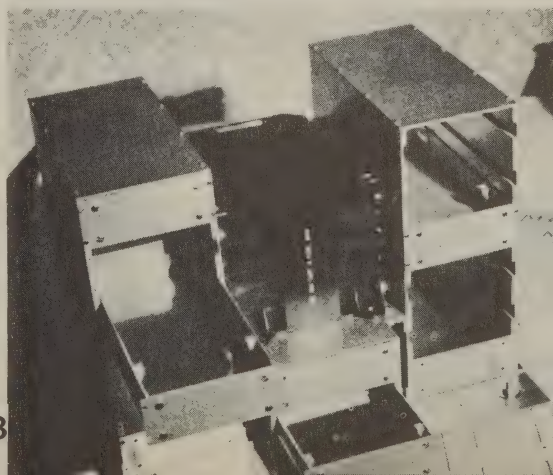


The electronics of A-O-B will be built in modular containers such as these.



Power will be supplied by this Nicad battery which will be recharged by solar cells.

The internal structure of Amsat-Oscar B.



Are You Ready . . .

for the Coming DX Openings?

BY WILLIAM I. DUNKERLEY, JR.,* WA2INB

DX POSSIBILITIES are in for a big improvement! You might have thought otherwise, what with declining sun-spot activity and all. But with a program now underway, you'll see the tables turned on this sun-spot cycle minima for unprecedented opportunities in amateur operating.

How? The answer is a communications satellite usable by the average ham. It will be able to keep a DX band live, and also open up additional frequencies not previously useful for long-haul work.

This is not an indefinite plan for "sometime in the future." The satellite, called Amsat-Oscar C (AOC) is now nearing completion. The National Aeronautics and Space Administration has already agreed to provide a "piggyback" launch. AOC is expected to be in use this year!

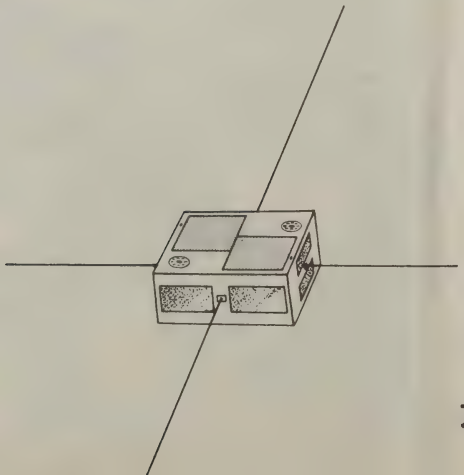
What Kind of Dx?

You should be able to work DX up to about 5000 miles away through this satellite. The map shown in Fig. 1 indicates the area of possible communication for a station located near Philadelphia. As you can see, over 100 countries are easily within range, not to mention all states including Alaska and Hawaii. To estimate what you'll be able to work, just envision a similar circle centered on your location.

Oscar will provide open-band conditions every day. The amount of time you hear the opening depends on your latitude. A station in Philadelphia will experience the DX for about 2-1/2 hours per day, whereas a station located at the North Pole will get 4-1/2 hours of action. In other words, the greater your latitude, the greater the openings. They will occur whenever the satellite passes within range of your station. The maximum usable time for any single pass will be about 25 minutes. The communication possibilities at any given moment will be within a circle of 5000 miles diameter, centered at a point on the earth directly below the satellite.

There will be plenty to work using the satellite. Amsat (with ARRL coordination) is planning a complete program of organized operating activities. Final details are not available yet, but you can expect exciting contest and award opportunities. How about an Oscar Worked All . . . award? An Oscar BPL? Or, maybe a Field Day bonus for Oscar operation from your FD site! Who knows, there may even be some new countries on through the satellite.

* Assistant Secretary, ARRL.



Amsat-Oscar C is expected to be the first in a series of long-lifetime satellites for use by radio amateurs. Frequencies in the 10- and 2-meter bands are utilized. The satellite will provide DX communications for amateurs around the world.

How Can I Get in on It?

Your ticket to DX via Oscar is not hard to come by. Here are some often-asked questions with answers to help you along:

★ "Won't it take an exotic high-powered microwave-type station to use this satellite?" Definitely not! Amsat-Oscar C was designed with the average ham in mind. It will use the ham bands at 28 and 144 MHz. As for power, you can use less than 50 watts and an antenna shorter than 10 feet.

★ "I'm set up for all bands from 80-10. Will I have to start from scratch with new equipment?" If you're equipped for 80-10 operation on cw or ssb (your preference!) you already have the basics for satellite DX via AOC. In future issues, *QST* will carry articles describing some accessories you can add. For example, a transmitting converter can put your signal on 144 MHz, the input band for the satellite. Your ten-meter receiver can be used as is for the down-link.[1]

[1] The frequencies on which the satellite transmits to you.

Fig. 1 — This is the area of communication possible via AOC for a station located in Philadelphia. A similar circle centered on your location will indicate what you should be able to work through Amsat-Oscar C.

★ "Will I have any special problems using my *transceiver* with AOC?" The answer to this question is yes and no. A transceiver plus transmitting converter will equip you for the appropriate bands, but not without certain problems. On the signals you will hear coming from the satellite Doppler shift will be present.[2] Each time that this causes you to retune the station you're receiving and working, you'll also move your own frequency. Then *he'll* have to retune, too. As a result, both stations will "walk" themselves across the band. This problem can be overcome with an "incremental" tuning feature on the transceiver, an external VFO, or an auxiliary receiver. Another problem of transceive-operation is that it will not allow you to listen to your own down-link. Use of an auxiliary receiver will overcome this drawback.

★ "If I get set up, will I have useful communication for more than just a few weeks?" Previous Oscars operated for only a few weeks. But AOC has a design lifetime of one year! And, Amsat has plans for another with similar characteristics to carry on from where AOC leaves off. So, your preparation for AOC should be useful for quite some time. Amsat-Oscar B, the satellite expected to follow AOC, could contain up to 3 separate repeaters. A brief description of AOB appears in March, 1971, *QST*, page 58.

★ "When the satellite is in operation, how will I know when I can use it?" A feature of the expected orbit is that it will bring the satellite near your location at about the same time every day. You'll get to know when to expect AOC DX much in the same way that you anticipate openings on the 80-10-meter bands. W1AW will transmit times at which the satellite will be near major cities. Reference data will be provided for those who wish more precisely to plot the location.

★ "Is this an fm repeater?" The AOC repeater will handle fm. In fact, it will accommodate any mode which appears in the input bandwidth. This type of a repeater is called a frequency translator. AOC receives 100 kHz at 2 meters for retransmission on 10 meters. Ssb or cw will be most efficient, but all modes (including RTTY, SSTV, etc.) should work.

★ "Will a fancy antenna-pointing system be required for tracking?" Best results will be obtained if your antenna is always pointed at the satellite. Movement of the antenna in elevation as well as azimuth[3] is necessary. But an easier alternative is available, providing adequate results. It is the use of a medium-gain antenna (about 10 dB for 144) pointed at a fixed elevation angle of about 30 degrees, rotatable in azimuth. The beamwidth of this antenna will be broad enough to allow satisfactory performance with most passes of the satellite. A ten-meter beam, located relatively close to the ground (a wave-length or less), will have a high enough take-off angle when mounted normally with its boom horizontal.

★ "How will I know if my signal is making it to Oscar?" You'll be able to hear your own signal coming back! The AOC repeater operates cross-band. So, you would transmit on two meters and listen on 10. If you keep your receiver on while you're transmitting, you can hear how effective your signal sounds through the repeater. This technique will allow you to adjust your antenna position and power output for maximum efficiency while using the satellite. In fact, by listening to your own down-link, you'll be able to hear any QRM which may come on while you're transmitting to allow moving to a clear spot.

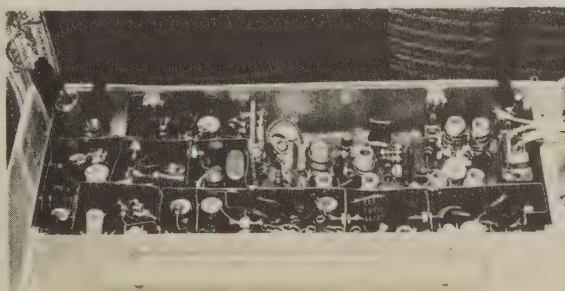
What Next?

Articles in future issues of *QST* will describe accessories which can be added to your station to equip it for AOC operation. As construction of the satellite is completed, and the testing phase begins, we'll have a more detailed description of the spacecraft and what it can do.

The AOC project is an undertaking of Amsat, the Radio Amateur Satellite Corporation. The group is affiliated with ARRL and receives modest League financial support. Amsat membership is open to those interested. The Amsat *Newsletter* sent to all members contains the latest information on activities such as AOC. For a membership application, drop a note and s.a.s.e. to Amsat, PO Box 27, Washington, DC 20044. QST

[2] A downward shift in frequency due to the motion of the satellite.

[3] The normal turning mode of ham antennas.



The electronics of a prototype Amsat-Oscar C repeater is shown. Its input is 100 kHz centered at 145.95 MHz with output centered at 29.50 MHz.

The use of vhf and uhf frequencies for intermediate and long distance communications has become possible through space communications techniques. There are basically two types of systems: passive and active. A passive system uses a celestial object such as the moon or an artificial reflecting satellite to return signals to earth. An active system consists of a space vehicle carrying an electronic repeater.

THE MOON AS A PASSIVE REFLECTOR

Communication by reflecting signals off the lunar surface has drawn the interest of an increasing number of amateurs in recent years, despite the considerable challenge such work represents. The requirements for earth-moon-earth (EME) communication are fairly well known. Overcoming the extremely high path loss of the EME circuit calls for close to the maximum transmitter power output obtainable with one kilowatt input, the best possible receiver, and very large high-gain antennas. The highest practical receiver selectivity is helpful, and visual signal-readout is often employed.

These requirements contribute their own problems. Narrow bandwidth demands exceptional frequency stability and calibration accuracy in both transmitter and receiver. High antenna gain means narrow beamwidth, in a system where a slowly moving target that is often invisible must be hit. And even when all demanding conditions are satisfied, the best one can expect is a signal barely distinguishable in the noise.

But the rewards are considerable, for the EME circuit provides vhf and uhf communications potential for any two points on earth where the moon is above the horizon. A surprising number of amateurs have accepted this supreme challenge, and before the end of 1970, all amateur bands from 144 to 2300 MHz had been employed successfully for lunar communications.

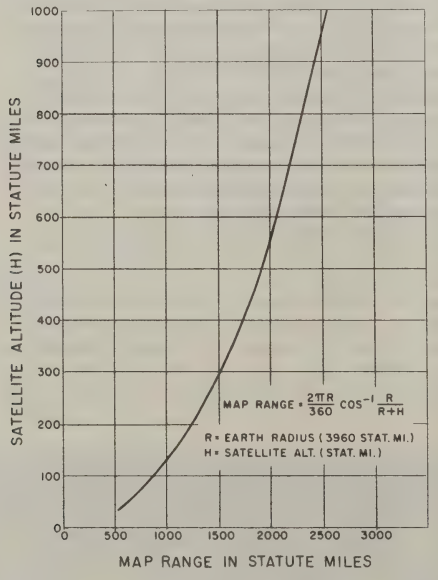


Fig. 15E-1 — Satellite altitude above earth versus ground station map range (statute miles).

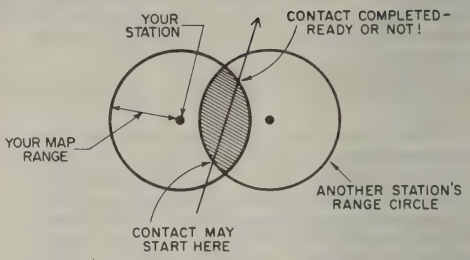


Fig. 15E-2 — Satellite passes through the range of two stations, enabling contact.

SATELLITES

Exciting communications possibilities are afforded through the use of amateur satellites. They function much in the same way as terrestrial repeaters, to relay signals over greater distances than normally feasible. (See chapter 14.) With satellites, the area is usually international in scope. Thus, DX communication on frequencies unable to support ionospheric propagation is possible.

Three amateur communications satellites have been orbited to date. Oscar 3, used in early 1965, was a 144-MHz in-band repeater; Oscar 4, launched in late 1965, repeated 144-MHz signals in the 420-MHz band; Oscar 6, launched in October, 1972, is a long-lifetime translator, repeating 144-MHz signals in the 28-MHz band. Oscars 1, 2, and 5 were beacon satellites for scientific and training purposes.

Current amateur plans for satellite systems involve the use of the 28-, 144-, and 420-MHz bands. Crossband repeaters are favored. Thus, expected combinations might be: 144 uplink, 28 downlink; 420 uplink, 144 downlink; or 144 uplink, 420 downlink. There is a trend toward designing amateur satellites with higher system gains (i.e., higher sensitivity and greater output). The objective is to permit the use of these satellites by average-sized amateur ground stations. Future satellite lifetimes of one year or more can be expected. Effort will be made for successive satellites to utilize similar frequency combinations to alleviate the need for equipment changes in ground stations.

A principal factor in determining how far one can communicate via a particular satellite is the orbit. Higher altitude orbits put the satellite within line-of-sight of greater areas of the earth. Fig. 15E-1 can be used to determine your map range for a satellite according to its altitude. For example, a satellite at 910 miles would give a map range of 2450 miles. For illustration, draw on a map a circle centered on your location with a radius equal to the map range. Each time the satellite is directly over any point

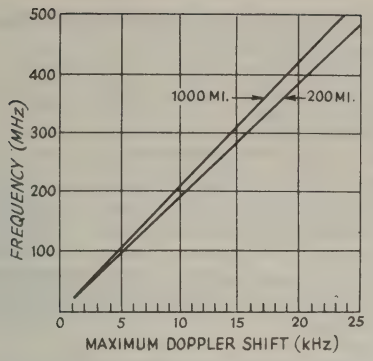


Fig. 15E-3 — Satellite transmitter frequency versus Doppler shift for satellite in 200- or 1000-statute-mile orbits. For a translator, use the difference between uplink and downlink frequencies as the "frequency."

within this circle, you will be able to use it for communication. Contact can be made with any other station having the satellite within its range at the same time. This is shown in Fig. 15E-2. Thus, the maximum map distance for communication would be about two times your map range.

The time duration for which a satellite will be within your range depends on two factors: the satellite's altitude and the distance between the subsatellite point (the point on the earth directly below the satellite) and your station. Higher altitude orbits increase the size of your range or acquisition circle, thus providing longer exposure to the satellite. Also, the longest duration for any given altitude will occur on orbits which pass directly over the station location. For example, a satellite in a 1000-mile orbit would be line-of-sight to a ground station for about 25 minutes on an overhead pass. At a map range of 1000 miles the duration would be 20 minutes, and at 2000 miles, availability would be about 10 minutes.

Conventional transceiver-type operation may offer some problems with satellites because of the Doppler phenomenon. Separate frequency control of the ground station's transmitter and receiver is desirable. (In some cases an "incremental tuning" feature on a transceiver will suffice.) Doppler is a frequency-shifting effect resulting from the motion of the satellite. It is a function of the transmitting frequency and the velocity of the satellite relative to the observing station. (Velocity is further a function of satellite's altitude.) Fig. 15E-3 compares Doppler shifts for frequencies up to 500 MHz for satellites in 200- and 1000-statute-mile orbits. The reason why Doppler shift requires a special consideration with transceiver operation is because two stations in contact would go through a series of frequency compensations, thus "walking" themselves across (and perhaps out of) the band! The frequency of a satellite moving toward a ground station appears higher than the actual satellite transmitter frequency. It drops as the satellite nears the ground station. At the exact point of closest approach, the observed frequency will be the same as the true frequency. Past this point, the satellite's signal will continue to drop lower in frequency as the satellite moves away.

There are two types of repeaters likely to be employed in future amateur satellites. A channelized repeater for fm would operate much like the ground-based fm repeaters used by amateurs; one station could use a channel at a time. Several contacts could be accommodated by a multichannel satellite. The other approach is called a frequency translator. It receives a segment of one band, say 100 kHz at 144 MHz, and retransmits the segment on another band, say 28 MHz. With a frequency translator, as many contacts as can be accommodated by the translator's bandwidth can take place simultaneously, and all modes can be used. Doppler shift from the fm repeater would be the same as expected for a transmitter on its downlink frequency. With a translator, however, the amount of Doppler shift is influenced by both the up- and downlinks. By employing a frequency inversion technique in the satellite's design, these amounts of Doppler will subtract; the resulting shift is then found from Fig. 15E-3 by using the frequency difference between up- and downlinks.

An aid to satellite communication is to monitor your own downlink signal coming from the satellite, while you are transmitting. This permits you to avoid interference from other stations, to compensate, where appropriate, for Doppler shift, and to adjust your transmitter power and antenna direction for maximum efficiency in sharing the satellite's output.

Best results in satellite communications are achieved when the ground-station antenna is pointed directly at the satellite. Movement of the antenna in elevation as well as azimuth is necessary. An easier alternative, providing adequate results, is also available. It is the use of a medium-gain antenna (about 10 dB) pointed at a fixed elevation of about 30 degrees and rotatable in azimuth. The beamwidth of such an antenna will

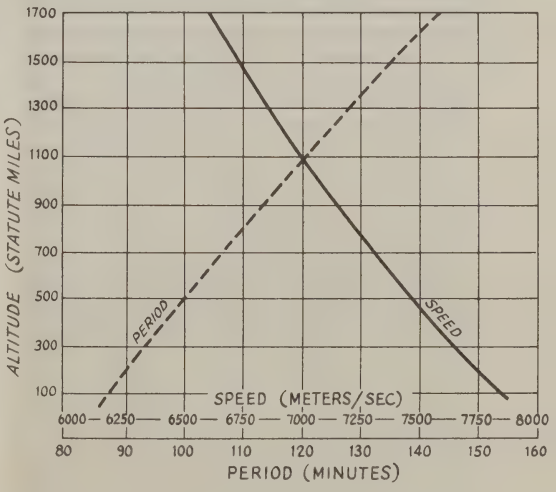


Fig. 15E-4 — Satellite altitude versus its period (time for one revolution) and speed.

allow satisfactory performance with most passes of the satellite. In the case of synchronous satellites, where the spacecraft maintains the same position relative to the observer, even the azimuth rotation can be eliminated – the antenna can be in a fixed position. However, greater antenna gain will most likely be needed in this case to compensate for the greater path loss from a satellite in such a high-altitude orbit.

Another antenna consideration for satellite communication is the use of circular polarization. Because the plane of a wave is rotated as it passes through the ionosphere, cross-polarization can occur between two linearly polarized (i.e., horizontal or vertical) antennas. This is called Faraday rotation. A circularly polarized antenna (such as a crossed-dipole, crossed-yagi, or a helix) at either the ground station or the satellite serves to minimize the effect.

Late Information

QST carries information about recent developments in Oscar. Since ground station requirements are dependent on the bands, modes, etc. used by the satellite, the amateur wishing to become equipped for space communication should consult ARRL headquarters to determine current amateur satellite plans.

Plotting Satellite Orbits

(Continued from page 11)

plot a hypothetical orbit and found that the orbit subscribed an arc across the map passing near but not over the North Pole. Also since the equator was in effect the edge of my map, I made a template with an index hole through which I could locate the North Pole. Now, by simply aligning the edge of my template on the equator and putting the Pole in the index hole, I can quickly trace that particular orbit.

From there on it's a matter of following *QST*'s directions to determine the proper beam heading and elevation to track the satellite.

The type of projection used on your map will affect the shape of the template you make. A Mercator projection for instance will give you the familiar orange-peel shape. Other projections might give you a shape more resembling a triangle. Regardless of the shape, however, it will always be the same for every orbit. Only the starting point will change.

Both the October *QST* article and this one are based on hypothetical data. It will be necessary to wait until the actual orbital data is announced in order to construct an accurate template. Since there is plenty of time between passes and since this whole job takes about half an hour, the template method bears consideration in light of the time that can be saved later by not having to lay out a series of points for each orbit. QST

EQUIPMENT RECOMMENDED FOR OPERATION WITH THE AMSAT-OSCAR-B RADIO AMATEUR SATELLITE

Three communications repeaters are being developed for the Amsat-Oscar-B series of amateur satellites. A selection has not yet been made as to what combination will be scheduled for the next satellite. This document has been prepared to better help you get ready for operation with this series of satellites.

Operation With the DJ4ZC/DJ5KQ 432-to-144 MHz Repeater

The DJ4ZC/DJ5KQ "H" repeater, described in the March 1971 issue of the "Amsat Newsletter," is a multiple-access, linear translator, receiving uplink signals between 432.125 and 432.175 MHz and repeating them between 145.975 and 145.925 MHz on the downlink. Sideband inversion occurs in the translation process (i.e., upper sideband becomes lower sideband, and vice versa).

To transmit signals through this repeater, a 432 MHz transmitter and antenna delivering 200-300 watts of effective radiated power (ERP) is recommended. *For best results ssb and cw should be used*. Although a-m, fm mcw and afsk will work with the repeater, these modes do not make efficient use of the limited repeater power and should be avoided. We recommend that a "transverter" be used to frequency-translate from 28 or 144 MHz to 432 MHz. In this way, a ten- or two-meter ssb or cw transmitter can be converted for VFO-controlled transmission on 432 MHz. For cw operation, an amplifier/tripler can be used to frequency-multiply the output of a two-meter transmitter to 432 MHz (see, for example, *Ham Radio*, Feb. 1970. A varactor tripler can also be used (see the ARRL *Handbook*). Perhaps the least expensive method of generating cw power on 432 MHz is to obtain a surplus 450 MHz fm transmitter strip and modify it for cw operation on 432 MHz. An article on this approach is planned by the ARRL Headquarters staff for a future issue of *QST*. It is strongly recommended that some provision for adjusting the power output of the transmitter be included. This is desirable to be able to adjust for the proper balance of satellite repeater power among users.

The antenna gain recommended for transmission to the satellite repeater will depend upon the transmitter output power. A 20-watt transmitter will require a 10-12 dB antenna gain to obtain the recommended ERP of 200-300 watts. A better approach would be to add a 200 watt power amplifier, in which case a dipole or ground plane should provide enough uplink signal to the satellite, and then there will be no need to keep the antenna pointed toward the satellite. The satellite antennas for this repeater will be circularly polarized, so that linear polarization (either horizontal or vertical) can be employed on the ground. Circular polarization can be expected to provide as much as 3 dB over linear and is probably worth the effort. Because the spacecraft will be magnetically stabilized, the orientation of the satellite will be constantly changing and the sense of polarization will depend upon ground station location. Stations in the northern hemisphere should use right-hand circular polarization, and those in the southern hemisphere, left-hand circular.

For receiving, any good two-meter converter should be suitable, and a two-meter receiving antenna having a gain on the order of 10 dB should provide good results. Linear polarization is satisfactory, but again, circular polarization can be expected to provide as much as 3 dB improvement (use right-hand circular in the northern hemisphere, left-hand circular in the southern hemisphere). If a 10-dB antenna is not available, a ground plane or crossed-dipole should provide detectable signals from the repeater's ten-watt PEP transmitter. The receiver should be capable of receiving ssb and cw (i.e., have a BFO, and a bandwidth less then 4 kHz) and most HF receivers should be suitable for the purpose. Transceive operation is *not* recommended because it is highly desirable that all stations be able to monitor their own downlink signals during the periods in which they are transmitting.

Operation With the Amsat Two-to-Ten Meter Repeater

The Amsat two-to-ten meter repeater, described in the March 1971 issue of the "Amsat Newsletter," is a multiple-access linear translator which receives uplink signals between 145.900 and 146.000 MHz, and retransmits them between 29.450 and 29.550 MHz on the downlink. Sideband inversion does not take place in the translation process (i.e., upper-sideband remains upper-sideband, and vice versa).

To transmit signals through the two-to-ten meter repeater, two-meter transmitter and antenna capable of providing 80-100 watts of ERP is recommended. *For best results ssb and cw should be used*. Flight tests with the repeater aboard aircraft demonstrated that a-m and fm signals are not very readable when relayed by the repeater, and they make very inefficient use of the limited repeater power (1-2 watts). Cw operation is generally possible with most two-meter transmitters. The most expedient means of achieving an ssb capability on two meters is through the use of a transverter which can up-convert the output of a ten, twenty or six-meter ssb or cw transmitter to two meters. Transverters of this type are available from several amateur radio equipment manufacturers, and are also described in the ARRL *Handbook* and the *VHF Manuals* published by the RSGB and ARRL. Transverters are also usable on cw, and have the added advantage that they provide a VFO capability if the basic transmitter already has a VFO.

The antenna gain recommended for transmission to the two-to-ten meter satellite repeater will depend upon the transmitter output power. A 20-watt transmitter will require a 6-7 dB antenna gain to obtain the recommended ERP of 80-100 watts. It would be preferable to use a transmitter in the 50-100 watt power output class, so that a

non-directional dipole or ground plane antenna toward the satellite will not be necessary. The satellite two-meter receiving antenna will be circularly polarized, so that linear polarization (either horizontal or vertical) can be employed on the ground. If circular polarization is available at the ground station, as much as 3 dB less transmitter power will be required for good communications. (Stations in the northern hemisphere should use right-hand circular polarization, and those in the southern hemisphere should use left-hand circular polarization).

Any good hf receiver capable of receiving ssb and cw on the ten-meter band should be suitable for receiving the ten-meter downlink signals if the receiver sensitivity is one-microvolt/meter or better and the local noise level does not exceed this level. A circularly polarized crossed-dipole should be adequate for receiving in low-noise environments, but a higher gain antenna, such as a three-element beam should provide better results, especially if it is circularly polarized. The satellite ten-meter transmitting antenna will be linearly polarized (a dipole) and Faraday fading can be expected to occur just as was the case for Australis-Oscar 5, unless a circularly polarized receiving antenna is used at the ground station. The use of transceivers is *not* recommended. Separate transmitting and receiving equipment should be used because it is highly desirable that all stations be able to monitor their own downlink signals while transmitting.

Operation With the Australis 144-to-435 MHz Fm Repeater

The Australis 144-to-435 MHz repeater is a channelized, hard-limiting repeater of the demodulation-remodulation type, and is designed to handle fm signals only (cw, ssb and a-m cannot be used with this repeater). The repeater receives fm uplink signals on 145.80, 145.85, 145.90 and 145.95 MHz, and retransmits them on 435.10, 435.15, 435.20 and 435.25 MHz, respectively, on the down link.

Tranamission of signal through the 144-to-435 MHz repeater will require a two-meter transmitter and antenna capable of providing a minimum ERP of 200-300 watts. *Only fm should be used*, with a deviation of $\pm$ 7.5 kHz. Available two-meter fm amateur transceivers and converted taxicab radios should operate satisfactorily, but a power amplifier should be used to increase the output power. If the power output is 50 watts, a 6-8 dB antenna gain should be sufficient. It would be advantageous however, to use a power amplifier in the 100 -200 watt power output class so that a non-directional dipole, ground plane or vertical antenna can be employed without requiring pointing toward the satellite. The satellite two-meter receiving antenna will be circularly polarized, so that linear polarization (either horizontal or vertical) can be used on the ground. The use of circular polarization on the ground will reduce the transmitter power requirements by as much as 3 dB (use right-hand circular polarization in the northern hemisphere, and left-hand circular in the southern hemisphere).

Reception can perhaps most easily be achieved through the use of a good, low-noise 435-to-144 MHz receiving converter, which will convert the 435 MHz downlink signal to 144 MHz where it can be received on the same two-meter fm transceiver that is used for transmission. These converters are commercially available. A high-gain circularly polarized receiving antenna should be used, with a gain of *at least* 12 dB, because this satellite repeater is expected to provide an output power of less than one watt per channel to individual linearly polarized monopole antennas.

DESIGN AND OPERATION WITH THE OSCAR 6 TWO-TO-TEN METER REPEATER

By Perry I. Klein, K3JTE

Introduction

The launch of AMSAT-OSCAR-C, designated OSCAR 6 in orbit, ushers in a new era in amateur radio. For the first time, amateurs will be able to communicate through an amateur satellite available for a year or more.

OSCAR 6 contains a number of interesting systems. A telemetry system provides data on 24 spacecraft parameters, transmitting them as Morse code numbers. A message storage unit called CODESTORE* enables the loading from specially equipped ground stations of various Morse code or RTTY messages. The messages are repeated until changed. A beacon operating on 435.1 MHz aids in tracking OSCAR 6, as well as providing a signal for use in checking out receiving equipment in a frequency range to be utilized in future OSCARs.

For most amateurs, probably the most intriguing system aboard OSCAR 6 is the two-to-ten meter repeater. This article is intended to provide sufficient detail on the design and operation of this device to enable amateurs to fully use its capabilities.

Development work on a linear two-meter input, ten-meter output repeater for use in OSCAR satellites began in late 1970 with the design assistance of Karl Meinzer, DJ4ZC. The repeater breadboard was completed in the spring of 1971; it is a linear frequency-translator designed to receive single-sideband and CW uplink transmissions in the frequency range 145.90 to 146.00 MHz, relaying them in the downlink frequency range 29.45 to 29.55 MHz. AM, FM, SSTV and RTTY signals can also be handled by the repeater, but with greatly reduced efficiency because unlike SSB and CW, repeater power is constantly required during all instants of each user's transmission. The use of FM with the repeater is discouraged because FM signals make very poor use of the repeater's limited power and bandwidth, reducing the number of amateurs who could otherwise use OSCAR 6 simultaneously. With minor modification on the other hand, it should be possible to key most FM transmitters so that they can be used on CW. In fact, this is perhaps the least expensive start in equipping to operate with the repeater, as two-meter FM transmitter strips are available surplus at low cost and can usually be modified readily for use on CW by keying one or more of the multiplier stages.

The Repeater Design

A block diagram of the two-to-ten repeater is shown in Figure 1. The repeater uses a 2N3478 RF transistor as a two-meter preamplifier, and another 2N3478 as the first mixer to mix the two-meter received signal down to 39.1 MHz. A 35.61625 MHz crystal oscillator output is multiplied by three to 106.84875 MHz and is mixed with the amplified two-meter signal to provide this 39.1 MHz first IF frequency. The signal is then fed to a 2N918 second mixer, which uses the 35.61625 MHz crystal oscillator a second time to mix down to a second IF frequency of 3.485 MHz, providing a gain of approximately 20 dB in the process.

The 3.485 MHz IF signal is then amplified approximately 35 dB in a single BF167 IF amplifier stage, after which it is up-converted to a frequency of 29.5 MHz in a 2N918 balanced mixer, using a 2N918 crystal local oscillator operating at 26.015 MHz. The balanced mixer achieves a gain of nearly 25 dB, and the signal level at this point is on the order of one milliwatt at 29.5 MHz. The signal is then amplified to a maximum of about 1 to 1.3 watts output using a 2N3866 driver and 2N3375 final amplifier. AGC voltage is developed in a three-transistor AGC amplifier, which senses the emitter current of the final amplifier and controls the gain of the BF167 IF amplifier.

*Both the Morse code telemetry unit and CODESTORE were designed and built by AMSAT's Telemetry System Manager, John Goode, W5CAY.

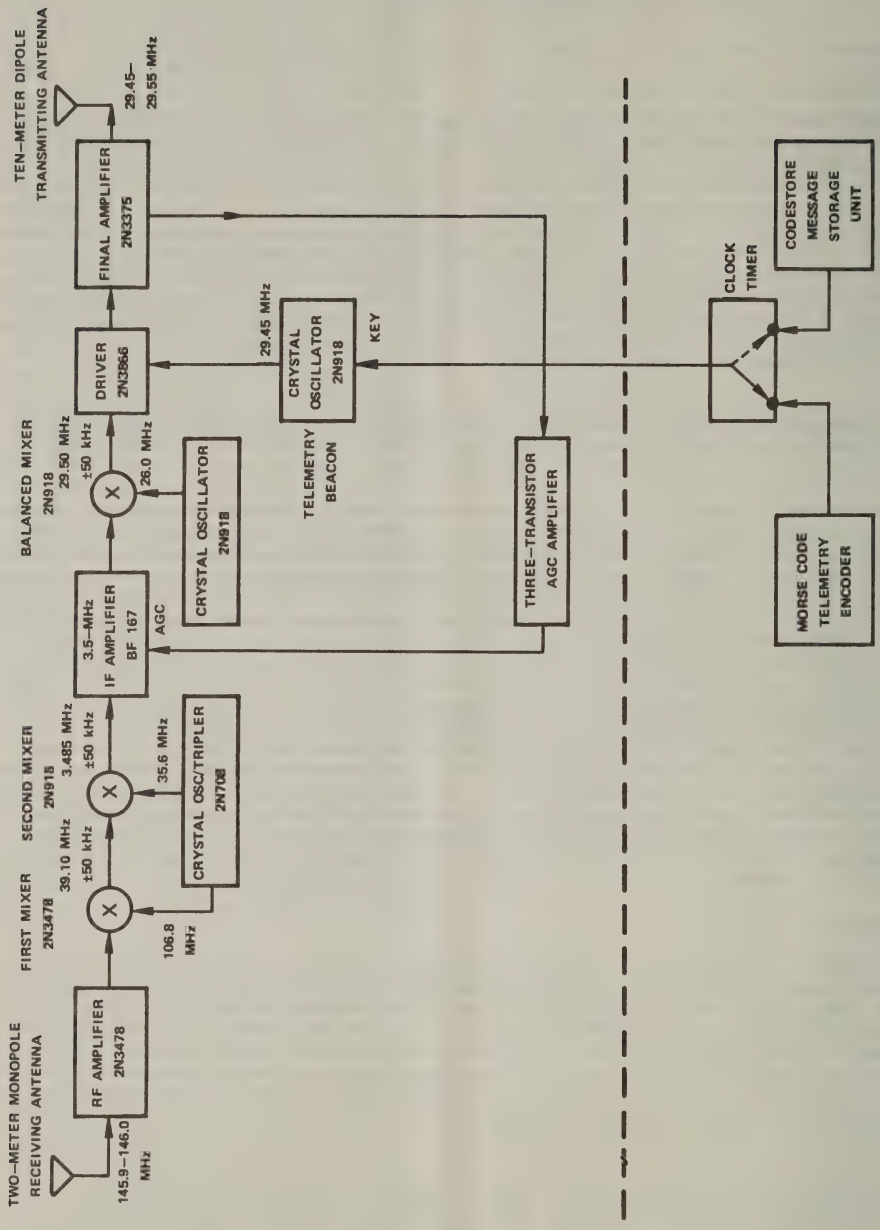


Figure 1

Block Diagram of the 2-to-10 Meter Repeater

The repeater also contains a beacon oscillator which operates at 29.45 MHz, the same frequency used by the last satellite, Australis-OSCAR 5. The beacon signal is injected at the input to the driver stage, and the beacon is keyed by the Morse code telemetry encoder or the CODE-STORE message storage unit, which are selected alternately at approximately 14 to 15-minute intervals by a clock timer device in the satellite.

Using the Repeater

The repeater is designed for linear operation and is capable of handling most forms of narrowband modulation, SSB, CW, AM, FM, RTTY and SSTV. SSB and CW are recommended primary modes of operation and make most efficient use of the repeater because a number of users can operate simultaneously, each taking different proportions of the repeater's power capability at a particular instant of time. Therefore, a higher average power level is available to each user since not all CW users are key-down at any given instant, nor are all sideband stations talking up to full power at any one moment. AM, FM and RTTY do not have this characteristic. Thus, stations employing these modes will each expend the available repeater power at all times, even when no intelligence is being transmitted.

To facilitate the most efficient operation of the repeater, all users are strongly urged to continuously monitor their own downlink signals. This is an operating technique previously rarely available to amateurs, but which enables each user to hear his own signal from the satellite as others hear it. It requires simply that a separate receiver and antenna be available for receiving one's own downlink signal on ten meters, while transmitting simultaneously on the two-meter uplink band. Such operation makes possible perfect break-in QSO's and roundtables, particularly on SSB, permitting full duplex operation. Unlike other forms of amateur communications, satellite communications with downlink self-monitoring permits each user to observe how the DX hears his signal, and he can then adjust his power and frequency to compensate for the satellite's distance and Doppler frequency shift. This is most readily done by observing the satellite's beacon signal level on 29.45 MHz and adjusting the power of the ground transmitter so that the repeated signal from the satellite appears to be the same level, either as read on an S-meter or as determined aurally. If the transmitter is VFO controlled, its frequency should be constantly adjusted by the operator while transmitting to keep the apparent downlink frequency constant in the presence of changing Doppler shift, which can be as much as $\pm$4.5 kHz for an overhead pass.

Spotting one's own downlink carrier is not always easy through the satellite repeater, and it is quite difficult to zero beat another station without careful dial calibration. One excellent method of getting a

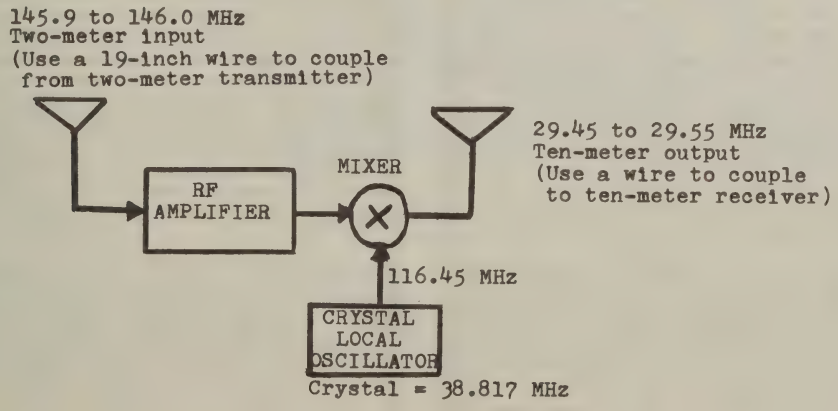


Figure 2

Two Meter Converter for Frequency Spotting

"frequency spotter" is to obtain a two-meter converter having either a 10 or 20 meter output and use it as a satellite repeater simulator in the shack. If the converter uses a 38.666 or 43.333 MHz crystal, replacing it with a 38.817 MHz crystal will convert locally generated two-meter signals in the 145.9 to 146.0 MHz uplink band to the correct frequency in the 29.45 to 29.55 MHz downlink band, so that spotting and zero beating can be accomplished without the signals leaving the shack. Figure 2 shows a block diagram of a repeater spotter for the shack. Because of Doppler shifts up to $\pm$4.5 kHz which will occur when using the actual satellite repeater, the spotter's frequency will be off by the amount of the Doppler shift. This can easily be corrected for by setting the transmitter frequency several kHz higher than the spotted frequency near the beginning of a pass, or several kHz lower than the spotted frequency near the end of a pass.

Operating Procedure

The procedure recommended for operating with the OSCAR two-to-ten meter repeater is as follows:

1) When the satellite comes within range, begin listening for the Morse code beacon signal on 29.45 MHz. Be sure to note the signal strength of the beacon signal. Since the beacon is A-1 emission, use your BFO to receive it.

2) Once you have located the beacon on 29.45 MHz, tune up the band and begin looking for signals from the repeater in the 29.45 to 29.55 MHz range.

3) When you are ready to transmit, choose a frequency within the 145.90 to 146.00 MHz uplink band and send a test signal, preferably a string of dots, on this frequency (f_2). Listen for your own signal retransmitted from the satellite on the corresponding ten meter frequency (f_{10}), found from the formula:

$$f_{10} = f_2 - 116.45 \text{ MHz} \pm f_{Doppler}$$

where $f_{Doppler}$ = +4.5 kHz near the beginning of an overhead pass
= 0 kHz at the middle of the pass
= -4.5 kHz near the end of an overhead pass.

For example, a signal transmitted on 145.92 MHz will be retransmitted on 29.47 MHz $\pm$ Doppler. This is where you should listen for your signal. If you can hear your own signal, you can be sure that others can hear your signal as well.

4) Adjust your transmitter power so that on SSB voice peaks or with a slow string of dots the repeated signal is approximately equal to the beacon signal level. This will assure that you take the correct share of the repeater power without overloading the repeater and running down the satellite's battery unnecessarily. Keep in mind that the power will be divided among all stations in the passband. An overly strong station will prevent other amateurs from simultaneously using the repeater if he does not reduce his power. He will also reduce the overall repeater gain, through AGC action, so that he will not be able to hear weaker stations who may be trying to call him. If you do not have a convenient method for directly controlling your power output, an alternative technique is to aim your antenna away from the satellite.

If you intend to operate with high power or use a large antenna array such that the transmitted output multiplied by the antenna gain is above 80 to 100 watts effective radiated power, then it is suggested that you operate slightly off from the regular passband of 145.90 to 146.00 MHz. The repeater has an "extended passband" feature in its design, that is the -10 dB response is $\pm$120 kHz from the center frequency (the passband is 240 kHz wide at the 10-dB down points). Therefore, if higher power stations will transmit between 145.83 and 145.89 MHz or from 146.01 to 146.07 MHz, their signals will be compensated for by the roll-off of the repeater response, and they will not take more than the correct portion of the repeater power. One benefit for doing this is simply a reduction

in QRM, since only high power stations can operate through the repeater on these extended frequency segments. Low power stations cannot easily overcome the additional attenuation of the passband roll-off and should operate in the normal repeater passband of 145.90 to 146.00 MHz.

Summary

In summary, listed below are the basic operating characteristics of the A-O-C two-to-ten meter linear repeater.

Input frequency range:	145.90 to 146.00 MHz for normal operation 145.83 to 146.07 MHz for extended passband operation
Output frequency range:	29.45 to 29.55 MHz for normal operation 29.38 to 29.62 MHz for extended passband operation Passband is non-inverting (i.e., upper sideband remains upper sideband and vice versa).
Beacon frequency:	29.45 MHz (same as Australis-OSCAR 5)
Beacon modulation:	Morse code (A-1 emission)
Repeater bandwidth:	100 kHz flat 120 kHz at 3-dB down points 150 kHz at 6-dB down points 240 kHz at 10-dB down points
Operating modes:	SSB and CW are recommended AM, RTTY and SSTV can also be used but with less efficiency FM is not recommended
Repeater power output:	1 to 1.3 watts CW into a half wave dipole
Input sensitivity:	Approximately -100 dBm (2 microvolts/m) for full output
Ground power required:	80 to 100 watts of effective radiated power produces full output from the repeater at a maximum range of 2,000 miles. (An 8 to 10 watt transmitter and 10 dB of antenna gain, or 80 watt transmitter and omnidirectional antenna should be adequate.)
Intermodulation:	20 dB down
AGC:	Up to 26 dB gain reduction 0.1 second attack time 2.2 second release time designed for highest efficiency with SSB
Ground receiver required:	Better than $\frac{1}{2}$ microvolt/m sensitivity for 10 dB (S+N)/N on 10 meters should be adequate. Dipole antenna can be used, but beam is preferable.

Acknowledgments

Many of the repeater design ideas came from Karl Meinzer, DJ4ZC. The prototype repeater was constructed by Wallace Mercer, W4RUD, and the flight unit was fabricated by Richard Daniels, WA4DGU. Jan King, W3GEY provided many helpful suggestions during testing. Components for the flight unit were obtained as a result of a grant to AMSAT from Project OSCAR, Inc.

HELIX ANTENNA GUIDELINES

By Richard L. McClain, W9MDW
K.O. Learner II, K9PVW

With more OSCAR satellites planned for the near future a high gain, directional antenna suitable for space-to-ground communication is desireable. A linearly polarized antenna is not ideal for this application because the tumbling of the spacecraft with its whip antennas causes periodic signal fading when cross polarization occurs. Crossed yagis reduces this problem but the beamwidth is narrow, dimensions are critical and impedance matching is time consuming with yagis. A better choice is the helix antenna which has the best compromise of minimum construction costs and difficulty, high unidirectional gain, wide bandwidth and circular polarization.

After determining the dimensions of the antenna from several rather standard formulas in the appendix, the next step is to select the materials. One of the best materials for the helix conductor is $\frac{1}{4}$-inch diameter copper tubing. Another is aluminum clothesline wire which is both lighter and cheaper than copper. Two or three strands of aluminum may be twisted together to increase the conductor diameter, if desired. One problem with aluminum wire is making the electrical connection of the feedline to the aluminum conductor. Both crimping and solder intended for aluminum has been tried successfully. If you are fortunate enough to find copper ribbon, this would make an excellent conductor. Whatever the conductor material, it must be supported on some type of framework. Small lumber has been used on 432 MHz, and higher frequency helix antennas with the conductor held in place by staples. Care must be taken to prevent the conductor from becoming egg-shaped. At low frequencies with a helix of several turns, lumber is probably not strong enough for the boom. In this case, electrical conduit may be a better choice with threaded rod used with insulators at the ends to support the helix. Figure 1 shows a plastic pipe tee section used as the insulator with a hose clamp to secure the twisted aluminum wire conductor. Threaded

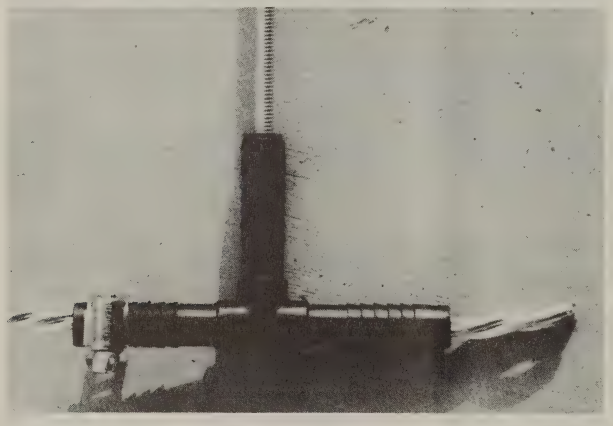


Figure 1

Plastic pipe tee used for insulator with threaded rod for standoff

rod of properly chosen diameter can be screwed directly into the base of the tee. Other insulating materials like lucite, plastic, fiberglass or even a cardboard cylinder would be excellent support for small helix antennas. A good rule to follow is to keep the material used to support the conductor to a minimum. The reflector screen material can be a solid sheet of metal but less weight and windloading can be had by using expanded metal, screen wire on a frame or just radials. The size and shape of the reflector screen can vary but approximately 0.9 wavelength diameter is common.

The biggest reason that helix antennas are not more common at UHF frequencies is the terminal impedance is not conveniently matched to standard coaxial cables. If the formulas provided in the appendix are followed by good construction practice, a terminal impedance of about 140 ohms must be

matched to the feedline. Two popular methods of matching are the quarter wavelength coaxial section and a tapered line matching section. The quarter wavelength coaxial section must be constructed with its characteristic impedance equal to the square root of the product of the antenna impedance and the transmission line impedance. For example, for a 140 ohm antenna and a 50 ohm feedline the matching section must be $\frac{1}{4}$-wavelength long at the operating frequency with an impedance of 84 ohms. This is constructed by using the formula: $Z_0 = 138 \log_{10} (b/a)$,, where b is the diameter of the outside conductor and a is the diameter of the inside conductor. This could be a standard piece of coax cable with the inner conductor replaced with a smaller piece of wire or a series of beer cans with a small piece of tubing centered within them by insulators providing the length and the ratio of inner to outer conductor diameters is proper. Use your imagination! Notice that the coaxial section will be a quarter wavelength long at only one frequency and limits the wide bandwidth characteristics of the helix. This may not be important for amateur work.

The other method of matching, especially with two or more helices, is a tapered line matching method which is constructed using the formula: $Z_o = 138 \log_{10} (4h/d)$, where h is the height of the conductor center from the reflector screen and d is the conductor diameter. Example: For a two helix antenna and assuming 140 ohm impedance at each helix feed point, the height of the feedpoint at the helix is found by:

$$138 \cdot \log_{10} (4h/d) = 140$$

$$\log_{10} (4h/d) = \frac{140}{138} = 1 \ldots \text{(almost)}$$

$$(4h/d) = 10$$

for 0.250 inch conductor

$$h = \frac{10 \times .250}{4} = 0.625 \text{ inch}$$

At the coax end: Notice that to match two parallel terminations to a 50-ohm feedline, each termination must be 100 ohms.

$$\log_{10} (4h/d) = \frac{100}{138} = 0.72$$

$$(4h/d) = 5.2$$

$$h = \frac{5.2 \times 0.250}{4} = 0.33 \text{ inch}$$

See figure 2 for a sketch of this example. For other conditions, just plug

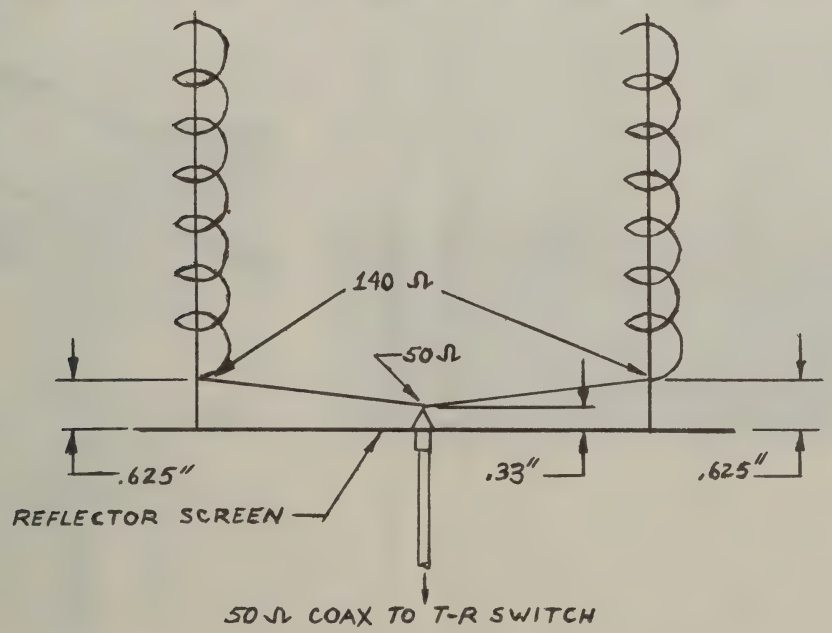


FIGURE 2. SKETCH OF TAPERED LINE MATCHING

in the appropriate numbers. The tapered lines should be equal in length and about one wavelength long. The attractive thing about the tapered line matching is that any number of helices may be easily connected to one feedline by adjusting the heights of the terminals. Also, it is not as frequency dependent as the quarter wavelength coaxial section. Keep the helices about one wavelength apart and feed them in-phase by feeding each one at similar points about the circumference of the helices.

A single ten-turn helix for 432 MHz would be about eight inches in diameter and 57 inches long. This would produce about 15 db of forward gain and a half power beamwidth of 30 degrees. Considering the simple construction and low cost it becomes an attractive antenna for any UHF enthusiast and it makes power requirements for satellite work minimal. Helix antennas used for satellite work in the northern hemisphere should have right-hand polarization and those in the southern hemisphere should have left-hand polarization. When viewing along the axis of the helix from behind the reflector screen, the turns will wind clockwise as they extend away from the reflector for right-hand polarization and counterclockwise for left-hand polarization.

Appendix

$$\text{Lamda} = \frac{300{,}000{,}000}{\text{Frequency in Hz}} = \text{Wavelength in meters}$$

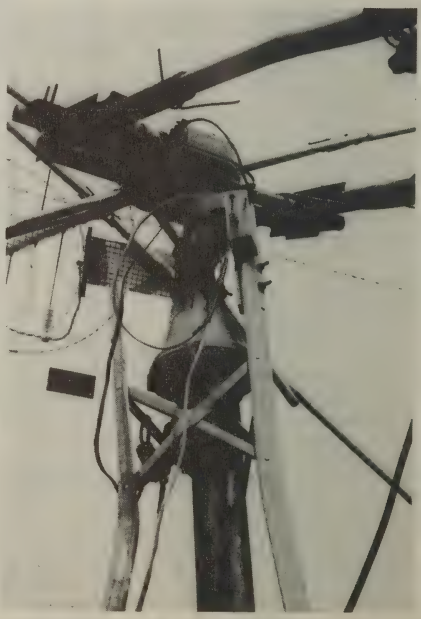
$$\text{Circumference of helix} = 1.1 \cdot \text{Lamda}$$

$$\text{Diameter of helix} = \frac{\text{Circumference}}{3.14}$$

Spacing between turns = Circumference x tangent of Alpha, where Alpha is the pitch angle which normally lies between 12 to 15 degrees.
Note: The spacing will be about $\frac{\text{Lamda}}{4}$.

Diameter of the conductor = 0.006 to 0.05 Lamda

$$\text{Length of conductor material} = \frac{\text{Circumference}}{\text{Cosine of Alpha}} \times \text{number of turns}$$



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A SIMPLE APPROACH TO OSCAR COMMUNICATIONS CALCULATIONS

By Carl W. Brown, W3LUL

With the launching of OSCAR 6 providing potential two-way satellite communications for the amateur, it becomes desirable for the serious participant in this mode to have available a simple technique for determining the mutual communication times between himself and other stations as well as the changes in beam headings during the pass. The method to be described permits the amateur to home-brew his own information from materials that are readily available. Satellite rise and set times derived are accurate to better than one minute. Vagaries of propagation are often worse thanthis. This technique is equally usable in both hemispheres or on the equator using only a single chart. The method is an outgrowth of a "quick and dirty" scheme to provide information on the times of passes of the previous Australis-OSCAR 5 over the principal cities of the world.

The technique involves plotting the satellite orbit on one piece of paper and the geographical locations of your station, the cities of interest, and your OSCAR receiving horizon on another. If one sheet is transparent then the two sheets can be aligned along the equator and the orbital plot moved to coincide with the equatorial crossing data supplied from W1AW bulletins and other sources. In fact, once a single pass has been acquired it is possible to do your own predictions for several days in advance. Although almost any pair of matched coordinate sheets could be used, a rectangular grid system was selected for this project rather than the fancy projections (of the earth) used by map makers, because the latter type of paper is not readily available. Data for plotting the orbit are taken from QST for October 1969, page 56, Table I. Although these preliminary Australis-OSCAR 5 data differ slightly from the true orbital time of 115 minutes duration and 388.8 degrees longitude advance for one revolution expected for OSCAR 6, the resulting errors are insignificant. An atlas provides the information on latitude and longitude for locating the cities of interest. Finally, unless one is mathematically inclined, a globe provides the easiest method of obtaining the geographical coordinates and directions to the horizon over which the satellite rises and sets at a particular location.

For the orbital data plot, a medium weight of paper stock, cross-ruled four lines to the inch with every fourth line heavy, is used. From the data table in the QST aforementioned article it is noted that the orbit carries the satellite to nearly 80 degrees of north and south latitude, while one revolution advances the longitude 389 degrees west (2 x 194.5 degrees). By choosing a scale factor of 20 degrees per inch, the minimum dimensions of this sheet for plotting one revolution are $8\frac{1}{2}$ x 22 inches. This permits the inking of one heavy line in the 22-inch direction as the equator and still having four inches of rulings above (north) and below (south) of the equator. Likewise, two inches of extra space are available at each end of the sheet beyond the 0 to 360 degrees length of the equator. Longitude values are labelled at 20 degree intervals along the equator, starting with 0-degrees at two inches from the right hand edge and progressing westward (to the left) through 360 degrees to 20. Also ink vertical (meridian) lines at 0, 180, 360. Label the north and south latitudes along the edges

at 20 degree intervals from the equator. Now plot the orbital data from the aforementioned table and connect the points with a smooth curve. Ink this curve for easy visibility through the transparent overlay which is to be prepared next. At right angles to the orbital path make light-weight lines at the points of two-minute time intervals.

The accompanying figure uses dashed lines rather than solid ones to distinguish the orbit as being plotted on the under sheet. The use of the time marks is evident. Be sure to label all values of time throughout the full 114 minutes (actual 115) of one revolution, starting with zero at the moment the satellite crosses the equator headed in a northerly direction. Data in the table are given for only the northern half of the revolution. However, the orbit is symmetrical so the plot of the southern hemisphere can be continued by reusing the same data again, but this time considering the latitude as south. Remember that adding even increments of time to 57 minutes lapsed time at the end of the first half of the orbit causes the time marks in the southern hemisphere to have odd values. If even values are desired one can always start at the 389 degree end of the orbit and plot the data going eastward along the equator.

It may be convenient to make additions to the plot. For example, the orbit can be extended backwards from zero into the southern hemisphere as shown in the figure. Also, for ease in predicting the next pass it is desirable to have that part of the orbital data beyond 360 degrees repeated on the right hand side of the page as is shown. Note that the next crossing of the equator is 29 degrees farther west than the previous orbit (actually 28.81 degrees).

The transparent overlay sheet with the geographical data is a similar size, or longer, page with faint rulings also at the quarter-inch intervals. In the absence of a single sheet of this size, a suitable substitute can be made by splicing together with transparent mending tape three pieces of $8\frac{1}{2}$ x 11" paper, such as fade out sketching paper. Be sure to register the major ruled lines if they are present. Unruled paper may be used just as easily if the orbital sheet with its grid markings is held precisely to this sheet during this construction and city location process. Ink the equator line to match the first sheet and rule off meridian lines at 0, 180, and 360 degrees of longitude as before. For maximum utility some may find it desirable to shift the coordinates of this page so as to have their own QTH at least 90 degrees from the edge. Label at 20 degrees intervals as before. From an atlas, select the geographical coordinates of the cities of the world which may be of interest and locate them on this overlay. No other geographical features are of interest so the distortion of this map is not evident. Be sure to include your own QTH. Values to the nearest whole degree provide adequate accuracy.

The next item to include on this sheet is the location of the horizon over which the satellite rises and sets at your QTH. For the sun-synchronous orbit of ITOS-launched OSCAR's this horizon is a circle (on the globe) located 2135 nautical miles from you. Nautical miles are used because each nautical mile is one minute of great circle arc, which means that there are 60 nautical miles per degree at the equator. Thus, this boundary is a line 35.5 great circle degrees distant. Since most of us live at middle latitudes the use of rectangular coordinate paper causes this circle of our horizon line to be quite distorted on this overlay. This can be seen from the figure. The only two easy points on this circle are those 35.5 degrees north and south of us on the meridian passing through our location. Locating the other points of this circle requires the assistance of a globe and compass. Adjust and secure the span of the compass to measure exactly 35.5 degrees along the equator of the globe. Then, with the compass centered on your QTH, scribe a circle on the globe. Make a table showing the latitude and longitude of each intersection of this circle with a major meridian or latitude line on the globe. Plot these data on the overlay. Connect all points with a smooth line. This is your listening horizon and any time the satellite passes inside this boundary it should be heard. A section of the overlay showing the satellite horizon for the writer is included in the figure as one of the solid lines. Note the severe distortion of the circle at higher latitudes.

Because of the narrow patterns of VHF beams, it is necessary to include beam pointing data. Use a rubber band or other aid to establish an east-

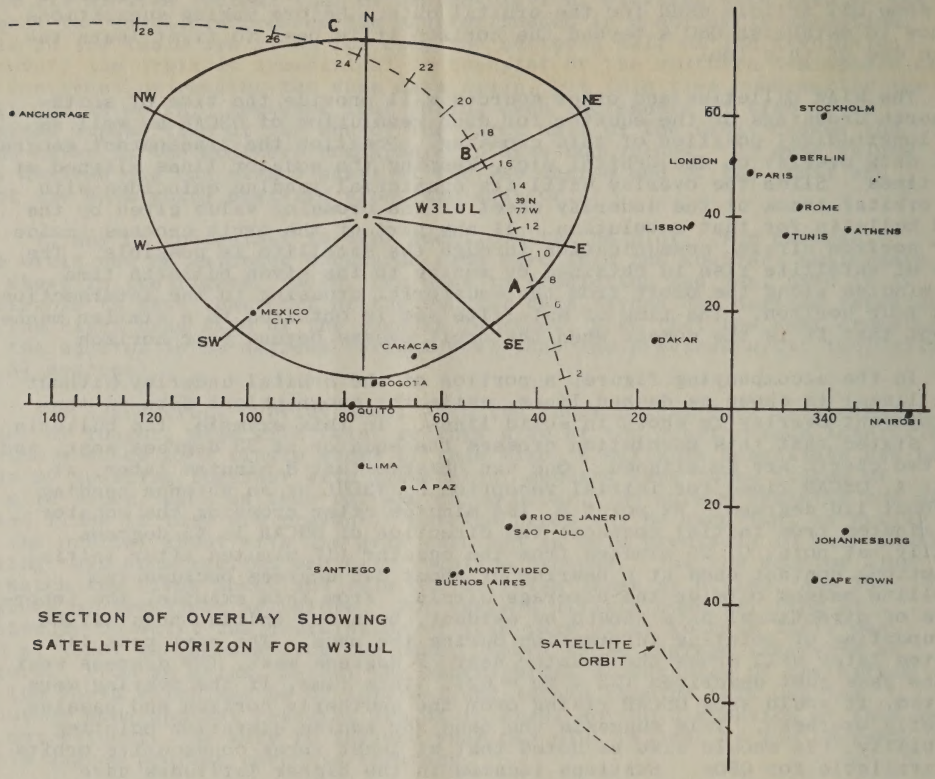
west great circle through your QTH on the globe. Note the positions of intersection with your horizon line. Mark these same coordinates on the overlay as E and W. Remember that if you live at 40 degrees of latitude this intersection does not fall on the 40 degree latitude line but is near 35 degrees. An east-west line connecting your location with these points on this chart would be a curved line; however, for most of us a straight line is an excellent approximation. As a minimum, locate these beam heading designations around the horizon line at 45 degree intervals. For the fellow with elevation pointing capability, additional contours within this circle would be desirable. Elevation data versus distance are given in Figure 2 of the same QST article used for the orbital data. Before making suggestions on how to establish QSO's beyond the horizon it is best to first learn the basic use of this tool.

The W1AW bulletins and other sources will provide the time of south-to-north crossings of the equator for each revolution of OSCAR as well as the longitudinal position of this crossing. Position the transparent geographical data overlay on the orbital plot, keeping the equator lines aligned at all times. Slide the overlay until its equatorial reading coincides with the orbital track of the underlay sheet at the crossing value given by the W1AW bulletin for that revolution. If any part of the orbit crosses inside your horizon circle, communication through the satellite is possible. The time of satellite rise is obtained by adding to the given bulletin time the minutes along the orbit from the equatorial crossing to the intersection with your horizon. The time of satellite set is obtained in a similar manner except that it is the moment when the orbit passes beyond your horizon.

In the accompanying figure, a portion of the orbital underlay (without grid lines) is shown as dashed lines, while the geographical data on the transparent overlay is shown in solid lines. In this example, the bulletin data stated that this revolution crosses the equator at 33 degrees west, and the two charts are so aligned. One can observe that 8 minutes later, at point A, OSCAR rises for initial reception by W3LUL at an antenna heading of about 110 degrees. At point B, $16\frac{1}{2}$ minutes after crossing the equator ($8\frac{1}{2}$ minutes from initial contact) the direction of OSCAR is 45 degrees. Finally, at point C, 25 minutes from the equator (17 minutes after initial reception) contact ends at a bearing of about 345 degrees because the satellite passes outside the coverage circle. From this example, the importance of directional data should be evident, both for initial acquisition and updating of pointing information during the pass. The next pass 115 minutes later will cross the equator near 62 degrees west, (29 degrees west of the pass just described (33 + 29 = 62). This time, if the overlay were shifted, it would show OSCAR rising over the southerly horizon and passing directly overhead. This suggests the need for adding elevation pointing capability. It should also be noted that at least three consecutive orbits are available for QSOs. Stations located in the higher latitudes have access to more passes.

Each station has its own distinctive horizon. For QSOs between two stations the satellite must be mutually visible to both. Therefore if contact with a specific station is desired a horizon circle must be prepared for the other station. For communication, the satellite trajectory must pass through this overlapping area of the two circles. For a station on the equator, such as at Quito, a circle of 35.5 degrees scribed with a compass would be an adequate approximation. If the other station's latitude is about the same as yours then it would suffice to trace your circle on another piece of transparent paper, mark the north-south line, cut it out and then center it on the station of interest. For example, the circle for W3LUL would also suffice for Lisbon. It should be noted that only a brief contact would ever be possible between the two locations. A momentary contact with Dakar would also be possible for the pass shown. On the next revolution Caracas would provide a potential communications window of $10\frac{1}{2}$ minutes, and Quito should be available for 8 minutes. Lima and La Paz offer brief possibilities. Remember that passes in the opposite direction, north to south, occur about 12 hours later.

In the absence of an aid like the one just described it would be difficult to make skeds for QSOs through OSCAR. Of course, one can always take pot luck, or tail-end the more competent stations in your area, assuming that they are kind enough to tell you where to point your antenna.



SECTION OF OVERLAY SHOWING
SATELLITE HORIZON FOR W3LUL

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